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Trip Chaining: Linking the Influences and Implications

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Trip Chaining: Linking the Influences and Implications

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Trip Chaining: Linking the Influences and Implications

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Transportation analysts have monitored with interest the emergence of trip chaining, or multi-purpose trip making, which is becoming a common method of travel for many households. As of 2001, 61% of all working age adults trip chained. From a policy perspective, this warrants attention as these 61% of adults who trip chain generate 68% of average daily vehicle miles traveled (VMT). In addition, most trip chaining is accomplished by automobile and generally alone or with other family members. Trip chaining research has focused predominantly on travel by workers and findings suggest that one reason for its increase is that workers are scheduling non-work activities into their work commute, largely to support household needs (primarily childcare but also for shopping and personal business).

Since the 1990s, significant federal funding has supported programs to improve air quality through reduced emissions. These include employer-based programs that seek to reduce VMT through ride sharing and the use of transit, along with incentives for doing so. The success of these programs is based on the flexibility of the commuter to

change his/her work mode. As indicated above, however, trip chaining is typically associated with decreased flexibility and almost in direct conflict with programs that encourage alternative commute modes.

This research identifies household, demographic, work, and activity setting factors that influence trip chaining in order to understand the related policy implications for employer-based programs that seek to reduce VMT through encouraging alternative commute modes. Using the 2001 National Household Travel Survey, a market segmentation identified trip chaining influencers. These were primarily the presence of children under the age of 16, worker status, more than one household adult, a high vehicle-to-worker ratio, and educational attainment above the high school level.

The findings indicate that while between 30 and 42% of workers commute in the traditional manner, employer-based programs can achieve greater returns if increased focus is placed on improving employer amenities. In addition, further VMT reduction can be achieved through new programs that target the household instead of the employer, as evidenced by the TravelSmart program in Australia and SmartTrips program in Portland, OR.

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Chapter 1 Introduction

1.1 BACKGROUND

Transportation analysts have watched with great interest a growing trend in travel patterns – that of multi-purpose trip-making or "trip chaining." While trip chaining has been noted in transportation literature from as early as the fuel crises in the 1970s (Hanson 1980; Pisarski 2005; Stopher and Meyburg 1975), up until the 1990s, it comprised a small proportion of all trips made. Most research on trip chaining focuses primarily on gendered differences in trip chaining and the mechanics of trip chaining (the types of trips chained, the order in which stops are made, etc.) in an effort to understand how the growing phenomenon could be better captured in travel demand models (Meyer and Miller 2001; Stopher and Meyburg 1975). Others study trip chaining within the context of the development of activity-based models ((Ettema and Timmermans 1997; Pinjari 2007) where the underlying question of what factors influence trip chaining has important implications for the application of these models in response to policy initiatives. In particular, those initiatives and efforts that focus on the traditional commute trip (travel directly between the home and work locations with no stops) will lose their effectiveness as Americans increasingly make stops on the way to and from work. The purpose of this research is to identify the factors that influence trip chaining in an attempt to understand the implications for the development of activity-based models in general and commute-focused programs in particular.

According to the 2001 National Household Travel Survey (NHTS), 61 percent of all working-aged adults make multi-purpose trips on an average weekday. These adults

tend to live in larger households with more members under the age of 16 as compared to non-chaining adults. It follows then that adults who trip chain make a significantly higher number of escort trips (to serve the needs of the passenger) – 0.65 average daily escort trips as compared to 0.03 average daily escort trips made by their non-chaining counterparts. Not all trip chaining is related to the presence of children however: 57% of adults living in households without children also report trip chaining. So while household composition appears to influence trip chaining, other factors are also at work.

The current level of trip chaining is hypothesized to be a reflection of the time constraints faced by working women, who must balance household and work responsibilities. This hypothesis has merit, as 65% of women trip chain. In addition, more than half of all workers (58%) trip chain, mainly on the way to or from work and generally to fulfill household obligations or serve household members. However, 56% of men also report trip chaining and the proportion of non-workers that trip chain is higher than for workers: 70% of all non-workers trip chain on an average weekday, as compared to 58% of all workers. Considering both sex and worker status, the distribution of working age adults who trip chain include 71% of female non-workers, 67% of male non-workers, 62% of female workers, and 54% of male workers. Thus, this widely accepted hypothesis that trip chaining is caused by the juggling of working women does not sufficiently explain the levels of trip chaining among men and non-workers.

This particular trend in travel behavior is important to note not only because of the change in the traditional commute, but also because research has shown that travelers who trip chain (regardless of worker status) are most likely to do so by automobile, and

often in single-occupant vehicles or as "fampools" with other household members (Concas and Winters 2007; McGuckin, Zmud, and Nakamoto 2005; Pendyala and Kitamura 2004; Wallace, Barnes, and Rutherford 2000).

This research seeks to identify the factors that influence trip chaining in order to better understand the policy implications of this growing trend. Since the 1990s, transportation professionals have developed programs to improve air quality by reducing vehicular emissions. Section 108(f) of the 1990 Clean Air Act Amendment identifies sixteen transportation control measures (TCMs) as important for improving air quality; from 2005 to 2009 more than $8 billion in federal funds are designated for these congestion mitigation programs. These programs can be broadly categorized as those focusing on the transportation infrastructure (e.g., designating high-occupant vehicle lanes, improving traffic flows, and restricting vehicles downtown during peak hours), specific travel modes (e.g., improving transit, reducing cold starts, and removing old vehicles from the roads), and employer-based programs (e.g., trip reduction ordinances, working with employers to allow flexible schedules and employer-based transportation management plans). This research focuses on the employer-based programs, which are designed to improve air quality through decreased vehicle miles traveled (VMT) generally via the promotion of ridesharing and transit as alternatives to driving alone to work (Concas and Winters 2007; McGuckin, Zmud, and Nakamoto 2005).

The success of these programs is based on the flexibility of the commuter to change his/her work mode. As indicated above, trip chaining is typically associated with decreased flexibility and is almost directly in conflict with programs that encourage

carpooling and transit usage in lieu of private automobile travel (Concas and Winters 2007; Wallace, Barnes, and Rutherford 2000). It is also associated with higher levels of VMT: the 61 percent of working age adults who trip chain are responsible for 68 percent of average weekday VMT. Understanding the factors that influence trip chaining can lead to a better understanding of how policy might be fine-tuned in this area in order to still meet VMT reduction goals in the face of changing travel patterns.

Because trip chaining reflects how individuals carry out their daily activities, understanding the factors that influence it is an important element in the development of activity-based models. Unlike the traditional four-step models, which focus on individual trips, activity-based models seek to reflect the decision-making process resulting in the observed travel patterns. By capturing the individual activity behavior as well as the interactions between household members, activity-based models can be used to evaluate the impact of proposed TCMs on improving air quality (Bhat 1999), such as parking management strategies (using the average length of the typical chained stop to set "short-term" parking limits) or commuter response to increased congestion within the context of their household responsibilities.

1.2 FACTORS THAT INFLUENCE TRIP CHAINING

There are several notable research efforts that address the trip-chaining phenomenon, largely in support of improving travel demand modeling efforts. It is important to note that the studies conducted thus far vary in focus – some consider the traveler, some the trip, others the type of stops made while trip chaining, and still others how many stops were made. Clearly the research question drives whether the analysis is

household, person or trip-based and the appropriate dependent variables. However, these variations in the focus lead to contradictions in terms of how the factors influence trip chaining. While this research is not intended to analyze and understand these differences, their existence must be noted.

Despite the varied focus of prior trip chaining studies, they also have many elements in common. These include how household composition, demographic characteristics, work constraints, and activity settings (both at the home and work) influence trip chaining. A summary of these studies is presented in Table 1.1 and discussed in this section.

Category	Variable	Research Evidence
Household	HH Size	Wallace et al (2000)[c]
	# Adults (-)	Bricka (2005)[c]
	# Children (+)	Bricka (2005)[c], Yalamanchili et al (1999)[d]
	Age of Children (+ ages 12-16)	Bhat & Zhao (2002)[c], McGuckin et al (2005)[a]
	Life Cycle (+ for households with children if adults work, - if adult does not work)	Chapin (1974)[a], Golob (1986)[c], McGuckin & Murakami (1999)[a], McGuckin et al (2005)[a], Misra & Bhat (2000)[c], Strathman et al (1994)[c]
	Income (+/-)	Bhat (1997a)[c], Golob (1986)[c], Wallace et al (2000)[c], Yalamanchili et al (1999)[d]
	# Vehicles/Worker (-)	Bhat (1997a)[c]
Person	Age (-/+/+ up to age 55 then -)	Al-Jammal & Parkany (2003)[a], Golob (1986)[c], Yalamanchili (1999)[d]
	Gender (+ for females)	Golob (1986)[c], McGuckin & Murakami (1999)[a], McGuckin et al (2005)[a], Misra & Bhat (2000)[c], Wallace et al (2000)[c]
Work	Work Duration (-)	Bhat (1997a)[c]
	Schedule Flexibility (+)	Damm (1980)[c]
	Car Required (-)	Wallace et al (2000)[c]
	Distance home to work (+/-)	McGuckin et al (2005)[a], Wallace et al (2000)[c]
Activity Setting	Density (+)	Misra & Bhat (2000)[c], Wallace et al (2000)[c]
	Presence of Rail (-)	Arentz et al (2001)[c]

[a] descriptives, [b] chi-square testing, [c] multivariate statistical analysis, [d] ANOVA

Table 1.1: Factors that Influence Trip Chaining

The influence of household composition and particularly childcare constraints figures prominently in the trip chaining literature. Whether measured by household size

alone (Wallace, Barnes, and Rutherford 2000) or by the number of children and adults in the household (Bricka 2005; Yalamanchili et al. 1999), this characteristic is consistently found to influence trip chaining in that larger households, particular those with more children, have higher trip chaining levels. Other studies (Misra and Bhat 2000; Chapin 1974; Golob 1986; Strathman, Dueker, and Davis 1994; McGuckin and Murakami 1999; McGuckin, Zmud, and Nakamoto 2005) found life cycle status and household structure to be significant influencers. More recent studies (Bhat and Zhao 2002; McGuckin, Zmud, and Nakamoto 2005) find the age of the children to be significant as well. Other significant household characteristics include income (Bhat 1997a; Golob 1986; Wallace, Barnes, and Rutherford 2000; Yalamanchili et al. 1999) and the number of vehicles per worker (Bhat 1997a).

Demographically, age has a significant influence on trip chaining (Golob 1986; Yalamanchili et al. 1999; Al-Jammal and Parkany 2003), with trip chaining levels increasing as age increases, up to retirement age. Gendered differences are consistently found to be significant throughout the studies, with regard to trip chaining rates, types of trips linked together, and time of day, with women chaining more than men (Golob 1986; McGuckin and Murakami 1999; McGuckin, Zmud, and Nakamoto 2005; Misra and Bhat 2000; Wallace, Barnes, and Rutherford 2000).

For those studies that focused on trip chaining influencers among workers, several variables are identified as significant. Bhat (1997a) finds work duration to be significant and Damm (1980) finds both work arrival and departure time flexibility as well as whether work began or ended outside conventional hours to impact trip chaining

propensities. Wallace et al (2000) indicate that a car required at work decreased trip chaining propensities (however, this may be because the underlying survey did not obtain details on work-related travel). The distance between home and work is significant as well, with trip chaining more likely the greater the distance between home and work (McGuckin et al 2005, Wallace et al 2000).

Only two studies could be located that considered trip chaining influencers among non-workers (Bhat and Misra 2001; Misra and Bhat 2000). These studies indicate that non-workers are most likely to chain shopping trips. In addition, non-workers who make escort trips do so at a higher level than workers, but were less likely to chain those trips.

The influence of activity setting on trip chaining was considered in some studies, with trip chaining decreasing as density levels increase. With regard to home location, Misra and Bhat (2000) find that non-workers living in urban areas are less likely to trip chain as compared to those located outside urban areas. Wallace et al (2000) have a similar finding with regard to households located within urban centers as compared to those outside urban centers. Arentz et al (2001) investigated the introduction of rail on travel patterns in a before and after study. They found that trip chaining decreased after rail was introduced. With regard to the work location, higher employment densities (particularly for retail and service industries) are found to be associated with increased trip chaining (Adler and Ben-Akiva 1979; Bhat 1997a). In addition, there are specific types of stops made that are associated with the work location rather than the home location (Hanson 1980), such as shopping, serve passenger, and eating out, suggesting that work is an anchor spatially as well as temporally (Damm 1980).

Most trip chaining studies focus on the purpose of the chained trips. The purpose of the chained trips for workers varies based on whether it is the trip from home to work or the trip from work back home. The home-to-work chain is largely comprised of serve passenger, personal business, and stopping for meal/coffee stops. On the work-to-home chain, the stops are for shopping, serve passenger, and personal business (McGuckin et al 2005). According to Golob (1986), trip purpose differs for full-time vs. part-time employees, with part-time employees making more personal business and serve passenger trips.

The current literature captures several important factors that appear to influence trip chaining. Some factors act as "constraints" in that they limit the time or resources available to the traveler, which may increase trip chaining levels. Other factors act as "energizers" in that they free up time or resources for the traveler, which may decrease trip chaining levels (Chapin 1974). These factors and their effect on trip chaining will be explored as part of this research.

This research extends the current literature in two ways. First, an attempt is made to introduce variables that more accurately capture the activity setting at the home location (at the census tract level). Given that prior research has shown that trip chaining is associated with making stops on the way to or from home, understanding the land use context of that home location is important. Since this research uses national survey data, the inclusion of home location descriptors is attempted through variables representing density, type of employment in the home census tract (a proxy for land use), and availability of transit (both bus and rail).

A second contribution of this research is the focus on all working age adults, not just workers or non-workers. This broader perspective allows for a new understanding of trip chaining influencers beyond the work commute and provides the foundation for future research into home-based (rather than employer-based) VMT reduction interventions that. It also will help in understanding whether the factors that influence the trip chaining propensities of workers are a function of that traveler being a worker or due to factors totally unrelated to his/her work status.

1.3 RESEARCH LIMITATIONS

There are three main limitations associated with this research. These include the fact that this analysis relies on survey data, that it is not an attempt to determine whether trip chaining should or should not be promoted, and that it is a policy-focused effort. Each of these limitations is discussed below.

First, this dissertation seeks to identify the factors that influence trip chaining and identify related policy implications. It accomplishes this through an analysis of the 2001 National Household Travel Survey (NHTS), sponsored by the U.S. Department of Transportation, as supplemented by 2000 Census data. The survey was conducted to identify demographic and travel behavior characteristics of Americans. As such, it focused on detailing "what" travel took place for an assigned 24-hour period, but not "why." Thus, the factors that influence trip chaining are identified through statistical association and not decision-making details explicitly stated by the traveler. In addition, the analysis focuses on working age adults at the traveler level, not at the household

level. Household level variables are used to describe the traveler, but household interactions are not specifically recognized in the model.

Second, this research does not seek to identify whether trip chaining is a travel behavior that should be promoted in order to achieve policy goals. Rather, it accepts trip chaining as a current travel pattern which is growing in magnitude and which influences the structure of the work commute, as well as travel among non-workers.

Finally, this analysis of trip chaining is evaluated from a policy perspective, not a modeling perspective. The distinction is as follows: policy questions focus on the traveler– demographic characteristics that help to identify levels of incidence and can be used to focus programs on specific population subgroups or the entire population. Modeling questions, on the other hand, seek to link demographic characteristics with travel patterns. Thus, modeling-focused studies include variables that describe the trip chaining itself, such as how many and what types of stops are linked together.

1.4 DISSERTATION STRUCTURE

The purpose of this research is to address the gap that exists between VMT reduction programs that rely on commuters making the traditional home-to-work commute and a commuter market that is responding to time and other constraints by scheduling non-work activities into the commute trip. In doing so, this research will also identify the factors that influence trip chaining among non-workers and discuss the related program implications. Through exploring trip chaining among all working age adults, this research will expand the current state-of-the-knowledge in this area by understanding which trip chaining influencers are work-related and which are based on

characteristics more fundamental, such as household composition, demographic characteristics, and activity setting.

This research is structured as follows: Chapter 2 provides context for this research through a literature review. The conceptual framework and research questions are presented in Chapter 3, followed by a description of the data used in the analysis in Chapter 4. Chapter 5 contains a presentation of the market segmentation, as well as its interpretation and application. The dissertation concludes with a discussion of the policy implications of the factors that influence trip chaining, as well as future research plans, in Chapter 6.

Chapter 2 Trip Chaining – Relevant Theory and Literature

2.1 INTRODUCTION

This research seeks to identify the factors that influence trip chaining in order to better understand the policy implications of this growing trend. An important element of understanding both why we travel as well as why travel differs across working aged adults requires an examination of travel behavior theory and existing studies.

This chapter is structured such that the relevant travel behavior theory is presented and discussed in Section 2.2. This is followed by a review of studies on the trip chaining phenomenon from a general analysis perspective, a travel demand modeling perspective, and a policy perspective in Section 2.3. Section 2.4 concludes the chapter with a summary of how this research benefits from the details gleaned as well as where this research fills gaps in the current literature base.

2.2 TRAVEL BEHAVIOR THEORY

Travel behavior theory provides the foundation for explaining the trip chaining phenomenon as well as why the factors that influence trip chaining are expected to vary based on the traveler characteristics. There are two parts to the current theory: the fundamental relationship between travel and activities and the role of constraints in shaping our travel. Each of these is discussed in this section.

2.2.1 Travel Allows Participation in Non-Home Activities

At the most fundamental level, people travel in order to participate in out-of-home activities (Ettema and Timmermans 1997; Hanson and Hanson 1980; Meyer and Miller

2001; Stopher and Meyburg 1975). The choice of activities is a function of people's basic desires (Chapin 1974; Hagerstrand 1970). The more people desire to participate in specific activities, the higher their propensity to do so, subject to specific constraints (Ettema and Timmermans 1997). Travel results from people choosing to participate in specific activities at destinations selected based on the quality of services and facilities available (or opportunities) within given spatial and temporal boundaries (Chapin 1974).

The economic theory underlying the choice of activities and resulting travel patterns is utility maximization (Damm 1980; Mansfield 1985). Households select and prioritize activities subject to budgets of available time, spatial adjacency, money, etc. The resulting activity patterns vary across households based on the factors that influence their utility maximization process, subject to their specific constraints (Ettema and Timmermans 1997, Stopher and Meyburg 1975).

According to Ettema and Timmermans (1997), activity patterns are shaped by the following phenomena:

1. Activities are performed with particular aims and objectives in mind.
2. Activities take place within a structured spatial setting that consists of services and facilities, opening hours, locations, etc.
3. Activities are prioritized based on their importance, frequency, and involvement of other people.
4. Activities are constrained due to time, money, available transport options, and hours of operation.

5. Activities have differing levels of flexibility in terms of when and where they can be performed.
6. Activities are sometimes routine or set in terms of time, location, involvement of others, etc. and sometimes specially planned events.

Explicitly missing from this theory of activity pattern development is the role of underlying demographic characteristics and household composition in the identification, selection, and organization of daily activities. Ettema and Timmermans (1997) recognize this concept in their summary of Chapin's "propensity factors." According to Chapin (1974), our basic desires drive the propensity with which we engage in daily activities and our desires can be energized or constrained. An example of an energizer is income: the more money we have, the more activity opportunities we have from which to choose. Constraints are those things that might prevent us from fully participating in specific activities, or require activity participation at a less-than-ideal location, and might include sex, income (or the lack thereof), work status, household responsibilities, and the activity setting in which one lives. These propensity factors are the linkage between who we are, what activities we pursue on a given day, and our travel patterns. They also serve to explain why travel patterns differ among working age adults.

2.2.2 Factors that Influence Activity Participation

In a perfect world, working aged adults would participate in all desired activities at ideal locations. However, there are only 24-hours in a day, and humans are physically limited in the distances that can be traveled within a given time period, regardless of travel mode. In addition, adults are constrained by responsibilities from home, work, and

other commitments. As introduced in the last section, Chapin (1974) identifies propensity factors that both energize and constrain our activity choices on a given day, thus moving the selection of activities from "ideal" to the closest thing realistically possible at the most feasible location.

The travel behavior literature focuses on the concept of constraints – those factors that limit utility maximization with regard to activity participation – and does not directly address energizers. As a result, in this literature review, only the term "constraint" will be used. This section is structured as follows: first, an introduction to the concept of constraints is presented, followed by a thorough identification of these constraints as presented in the related literature. A discussion of how these details affect the expected outcomes of this research is presented in Section 2.2.3.

2.2.2.1 Introduction to Constraints

We travel in order to participate in activities. However, humans are limited in the number of activities that can be undertaken in any given day. According to Hagerstrand (1970), humans are constrained physically (we can only see, hear, and reach so far), temporally (there are only 24-hours in day), and spatially (where we live and work being the main anchors in decisions of where to perform other activities). There are also "authority constraints," which limit activities by law, rule, or other regulations (Hagerstrand 1970). An example of an authority constraint is the hours of operation for public schools, which often guarantees conflict for working parents (Harvey 1997). For commuters, if there are only 24-hours in a day and work takes up at least one-third of those hours, the noted trends in trip chaining suggest that many plan their commute such

that they can maximize the accomplishment of household and childcare responsibilities while they journey to or from work.

It is also important to note that constraints vary in terms of influence on travel behavior. The temporal constraint is more rigid than spatial constraints (Pendyala 2002), with work requirements imposing a greater time constraint than non-work activities (Bhat and Singh 2000; Damm 1980; Harvey 1997). This means that if an adult is required to work from 8 a.m. to 5 p.m., he/she must arrange and prioritize household duties and other desired activities around the work hours. Harvey (1997) indicates that constraints can also vary based on socio-economic factors such as age, sex, employment status, family status, and income.

The literature focuses on four specific types of constraints: household, person-level (or demographic), work-related, and activity setting. Summaries focused on each area are presented below.

2.2.2.2 Household Constraints

In terms of household constraints, there are two types: those that exist simply from being a household and those that exist as a function of how responsibilities are divided among the household members. These are summarized below, along with a specific look at the influence of the childcare constraint.

Household Linkages. For all households with two or more persons, linkages among the household members exist that create constraints (Damm 1980; Ettema and Timmermans 1997; Hagerstrand 1970; Srinivasan and Bhat 2006). These linkages limit the flexibility each member has in structuring his/her travel and vary based on the level of

shared activities or responsibilities (Petersen 2004; Vovsha 2004). The strength of these linkages is expected to vary based on factors such as job location, the destination for the linked activity, and the ability of household members to travel independently (Vovsha 2004). Another factor influencing joint household activities is the overall level of employment, with higher employment levels suggesting lower interaction levels among the workers (Gliebe and Koppelman 2002).

Household Responsibilities. The level of household responsibilities for each household member varies based on household composition, ethnic background, income levels, employment status, education levels, and most notably sex (Bhat, Srinivasan, and Axhausen 2004; Hanson and Hanson 1980; Hochschild 1989; Petersen 2004; Ren 2005; Vovsha 2004). It also varies based on cultural background and the power relationship within the household, with higher-educated couples having a more equal share of the household duties but the woman still having a higher level of responsibility (Hochschild 1989, Petersen and Vovsha 2004). In addition, Petersen and Vovsha (2004) found that when there are two workers in a household, the assignment of responsibilities is an inverse function of the hours worked: the person working more hours had fewer household responsibilities.

Childcare Constraints. Household responsibilities are present in each household regardless of composition but childcare constraints vary, not only in terms of presence but also with regard to the distribution of childcare responsibilities among household members. This distribution is primarily according to the age of the youngest child

(Gliebe and Koppelman 2002; Rosenbloom 1987), the presence of other household members (Bricka 2005), and income levels (Gliebe and Koppelman 2002).

Most studies show that in two-parent households, the mother is the primary caregiver, even if she also works (Golob 1997; Harvey 1997; Hochschild 1989; Stoltz-Loike 1992), with one study estimating that women spend about 35 hours per week on childcare duties compared to only 17 hours for men (*Working Family Values Factoids* 1998). In the case of single-parent households, the sole parent is by default the caregiver although he/she may rely on extended family and inter-household linkages for assistance.

In sum, the childcare constraint may or may not be present, and if it is present, it is likely to differ in terms of impact on household travel behavior based on the age of the children (Gliebe and Koppelman 2002; Rosenbloom 1987; Shiftan 2002). This constraint is often reflected in the need to drop off or pick-up children at daycare/school (with strict time requirements – see McGuckin et al 2005, Vovsha and Petersen 2005), escorting children to extracurricular activities (Rosenbloom 1987, Gliebe and Koppelman 2002) or taking them to the doctor/dentist (Petersen and Vovsha 2004).

2.2.2.3 Demographic Constraints

Demographic constraints are those that describe the working aged adult traveler. The dominant factor in the literature is gender. Other demographic characteristics include work status (which is addressed in the next section), minority status, and age.

The literature points to a strong gender constraint, largely due to the fact that women tend to bear the greater level of responsibility in both household chores and childcare, even if both adults in a household work full-time (Clifton 2001; Hochschild

1989; Petersen 2004; Shelton 2000). There are indications that men are sharing more of the household tasks, suggesting that this gendered effect may be lessening, particularly among higher educated adults (Achen and Stafford 2005; Bianchi et al. 2000).

Focusing on women for a moment, supporting evidence regarding how women balance home and work responsibilities was presented in an analysis of the 1995 Nationwide Personal Travel Survey data. This study found that not only do women make more trips to perform household duties than men do, but also women are more likely to chain those trips into their work commute (McGuckin and Murakami 1999). Other studies focusing on low-income working mothers found that they were most likely to perform household-related errands during the lunch hour or on their way home from work (Clifton 2001). In sum, whoever bears the greater burden of household responsibility should be expected to trip chain their travel in a way that allows them to accomplish their duties in an organized manner (Levinson 1997; McGuckin and Murakami 1999; Taylor 1997).

2.2.2.4 Work Constraints

Results of prior studies indicate that when planning activities and associated travel, the worker will anchor his/her activities about the work constraint (Hanson and Hanson 1980, Bhat and Singh 2000). In scheduling daily activities, workers first allocate the time to be at work then prioritize other errands and activities in the remaining time. Thus, the work hours and location becomes an "anchor" about which all other activities and related travel are arranged. In juggling work and household responsibilities, commuters have been found to have higher trip chaining levels on the journey home from

work rather than on the journey in to work (Bricka 2004a; Jou 1997). The work constraint itself is comprised of two components: tangible and intangible. The tangible work constraint is measurable and often present in the survey data. The intangible work constraint is not as easy to measure, although it is present for most US households with workers. Each of these is discussed below.

Tangible Work Constraints. Tangible work constraints involve those aspects of the job that are measurable. These include the number of hours worked, the actual start time at work, the work location (at a fixed location or not), the flexibility of the work schedule, type of shift (typical 8 to 5 or something else), type of employer and occupation (Bhat and Singh 2000; Jou 1997; Menino 2002; Sall 2004; Yeraguntla 2005). The work constraint appears to be directly linked with the household constraints. Blumenberg (2004) found that, regardless of occupation type, "single mothers prefer employment close to their homes in order to more easily shoulder household responsibilities."

In addition, the work location itself can act as a constraint. Employment density, development density, activity opportunities in close proximity to the workplace, and the distance from the employment site to the central business district were found to influence choice of work mode as well as the presence of trip chaining before or after work (Bhat and Sardesai 2006; Douglas and Evans 1997; Mannering 1990; Shiftan 2002).

Intangible Work Constraints. There is a second aspect to the work constraint that also influences work-related decisions – job security. While it cannot be directly measured, it does impact household activity and travel patterns.

Most jobs and related careers in the US today are still based on the traditional "male breadwinner" template of the 1950s, which assumes that workers can travel directly between home and work, and work uninterrupted for long hours (Moen 2001). The social exchange in the 1950s was that employers offered job security in the form of pensions and good benefits, and performance was rewarded with promotions. In return, employees put in the hours, had job security, and tended to start and end their careers at the same company.

In today's workplace, workers juggle, balance, and make trade-offs to meet employer expectations in hopes of a promotion, but without guarantee of that promotion or even job security through retirement age. Most employers no longer offer pensions or the job security that came so readily in the 1950s, nor, depending on the size of the firm, are they required to offer basic benefits or health insurance. For lower income workers, a sick child or car trouble can translate into a lost job (Moen 2001).

The work constraint influences household activity and travel patterns directly through tangible work requirements and indirectly through intangible factors such as concerns over job security. While it may not be possible to directly capture the intangible constraints in the travel survey data, understanding the influence of job security (or the lack thereof) aids in interpreting household activity prioritization.

2.2.2.5 Activity Setting Constraints

Underlying household travel patterns is the transportation network, the land-use development pattern, and other social "norms" which comprise the activity setting (Harvey 1997). The activity setting includes the array of mode choices and viable

locations at which the necessary activities can be conducted, as well as the times during which the activities can take place.

The activity setting provides a contextual basis for how and why activity and travel patterns might vary across regions (Harvey 1997). For example, transit service and accessibility in cities that grew up around transit (such as New York or Washington DC) is much different then service and accessibility in those cities that developed around the auto (such as Los Angeles or Houston) (Blumenberg 2004). Thus it can be expected that travel by transit will vary between those two different activity settings. The activity setting also includes factors such as variations in hours of operation for particular services. For example, childcare in Austin typically ends by 6 pm, but in Las Vegas or other areas with a high proportion of night shift workers, 24-hour care may be available.

Authority Constraints. Authority constraints are those laws, rules, and regulations that imply that particular activities can only be performed at particular times and/or locations (Ettema and Timmermans 1997). These authority constraints shape activity choice and related travel through regional conventions of store hours and days of operation, school and daycare hours, and even land use development regulations which dictate what type of development can exist and where (Harvey 1997).

Transportation Constraints. The transportation system component of a region's activity setting can greatly impact household travel behavior. The availability of alternative modes such as bus-transit or rail can serve to increase accessibility or limit access, depending on the structure of the system, service characteristics, and the level of accessibility in traveling between specific origin-destination pairs (Blumenberg 2004).

Opportunity Constraints. The viable locations at which activities can be performed are referred to as "opportunities." This includes the array of services and facilities provided at the quality level desired by the traveler (Ettema and Timmermans 1997). For smaller metropolitan regions, limited opportunities for work, shopping, or medical services might lead households to accept longer commutes or schedule specific day trips into larger urban areas to receive higher quality medical care. For households in larger urban areas with more varied activity settings, decisions about which activities to accomplish after work might require optimizing among several viable locations.

The opportunity constraint within an activity setting may also serve to facilitate mode choice, particularly in relation to land use development choices. A Victoria Transportation Policy Institute study (Litman 2007) of the impact of land use development on mode choice concludes that Smart Growth land use policies at the local level have the potential to reduce per capita vehicle travel 3-15% through encouraging more infill, more compact development, and smarter development (such as locating schools, parks, and shops within neighborhoods). Therefore, the land use component of an activity setting in a region can indicate not only opportunity but also feasibility when considered in conjunction with travel mode options.

2.2.3 Constraints and Trip Chaining

In sum, from a theoretical point of view, we travel in order to participate in out-of-home activities. These activities are determined based on our basic desires and our characteristics, which serve to constrain or energize the activities in which we participate. In addition, as humans, we face physical, time and space constraints, which limit where

we can perform these activities. Throughout the literature, the time constraint is most often listed as the underlying cause of trip chaining, particularly for working women who tend to have a larger share of the household responsibilities that must be accomplished in addition to work responsibilities.

The theory underlying travel behavior does not explicitly take into account the traveler's characteristics in selecting the activities to be performed on a given day. However, the existing studies on constraints clearly find that travel behavior is influenced by traveler characteristics – most notably sex but also household, work, and activity setting factors. The theory investigated through this research is that these constraints are what cause differences in travel patterns across working age adults, most notably trip chaining.

2.3 TRIP CHAINING STUDIES

There are several notable efforts that address the trip-chaining phenomenon. These studies vary in terms of analytic tools (descriptives, canonical correlation analysis, logit and Poisson models) as well as focus (workers, commute trip chains, non-work related trips, spatial distribution, etc). It is important to note that the trip chaining studies conducted thus far vary greatly in terms of dependent variables– some consider the traveler, some the trip, others the type of stops made while trip chaining, and still others how many stops were made. Clearly the research question drives whether the analysis is person or trip-based and the appropriate dependent variables. However, these variations in the focus lead to contradictions in terms of the factors that influence trip chaining and policy implications. The purpose of this section is to review trip chaining studies to date,

in order to identify similarities and differences in structure and focus, and how those similarities or differences influence the findings related to trip chaining.

In the first part of this section, trip chaining is defined. This is followed by a summary of relevant studies with regards to how they have helped inform our general understanding of trip chaining, incorporation of the phenomenon into activity-based travel demand models, and implications for policy. The section concludes with a discussion of how this research benefits from the prior studies.

2.3.1 Trip Chaining Defined

"Trip chaining" is used to describe a travel pattern that includes a series of related trips. There is no formal agreement on what exactly constitutes a "trip chain" or how to systematically identify one in a data set (McGuckin et al 2005), a problem first noted by Thill and Thomas (1987) as the root cause of limited progress in modeling this phenomenon. Throughout the literature considered in support of this research, only one article operationally defined trip chaining: "a sequence of trips bounded by stops of 30 minutes or less" (McGuckin and Nakamoto 2004). Developed by the FHWA for application in the National Household Travel Survey data, this definition of trip chaining is based on the length of time spent at each destination without regard to trip purpose. While other articles provided similar working definitions of trip chaining (essentially multi-purpose trip-making), none provided operational details of how the chains were identified within the data.

Although the literature does not delineate how the trip chains are constructed for analysis purposes, most trip chained data is described using two aspects: time of day and

trip purpose. Most time of day groupings are centered about the commute or workday (Hanson 1980, Damm 1980, Bhat and Singh 2000). McGuckin et al (2005) consider trip chaining time periods that are distinct from the actual commute: before 6 am, 6-8:59 am, 9am-11:59 am, 12-2:59 pm, 3-5:59 pm, and 6 pm or later.

In terms of trip purpose, activities are generally analyzed in the categories of mandatory or subsistence (work or school), maintenance or non-discretionary (household and childcare related), and discretionary (leisure) (Gliebe and Koppelman 2002; Golob 2000; Mohktarian 2006). Some descriptive studies considered the broadest range of trip purposes possible (McGuckin and Murakami 1999, McGuckin et al 2005). The oldest studies (pre-1990s) categorized all trip purposes as work or leisure (Golob 2000).

2.3.2 Analysis of General Travel Behavior

Within the typology of trip chaining studies, the earliest literature investigated the trip chaining phenomenon simply to understand more about the travel pattern itself or to establish linkages to traveler characteristics. These studies helped to advance the state-of-knowledge regarding trip chaining in general.

For example, in analyzing typical travel measures such as trip frequency, distance, etc, Hanson and Hanson (1981) confirm that trip chaining is a different type of travel pattern as compared to simpler travel, with the characteristics of longer multi-stop trips being distinct from those that describe shorter single- or double-stop trips. According to Golob (1986), the most effective predictors of activities carried out through trip chaining are life cycle, age, and income. Several studies emphasize the importance of household role in understanding variations in travel patterns and trip chaining in particular, with

women trip chaining more to accomplish shopping and serve passenger needs (Golob 1986; Hanson and Hanson 1981; McGuckin and Murakami 1999). In particular, Yalamanchili et al (1999) found that while women trip chain more than men, men who trip chain have longer chains (more stops) with each activity tour that they make.

The earlier studies also confirmed that shopping, personal business, and serve passenger trips were most likely to be chained (Hanson and Hanson 1981, Golob 1986, Yalamanchili et al 1999) while social/recreational trips were least likely to be chained (Yalamanchili et al 1999, Misra and Bhat 2000). In addition, Misra and Bhat (2000) note that non-workers are also less likely to chain serve passenger trips.

It is now widely accepted that trip chaining is a complex travel pattern and distinctly different from simple non-stop travel, that household roles and responsibilities shape this travel pattern, and that it can and does vary based on sex, the presence of children, age, and density. The literature has also shown that the trip purposes with the highest propensities to be chained together are those related to household responsibilities – work, personal business, and shopping trips.

2.3.3 Analysis to Support Travel Demand Modeling

Trip chaining has received a great deal of attention by travel demand modelers, largely because of the challenges entailed in adequately replicating and forecasting this pattern within the context of a travel demand model, which requires "complex relations and interdependence of timing, duration, location, frequency, and sequencing of activities, nature, number of stops and trip length" (Thill and Thomas 1987). Some studies have focused on the decision-making process behind the selection and

organization of activities, others on the travel pattern itself. All modeling related studies are conducted with the goal of informing the development of the more complex activity-based models, as the traditional four-step travel demand models cannot accommodate trip chaining (Adler and Ben-Akiva 1979; Goulias, Pendyala, and Kitamura 1992; Misra and Bhat 2000; Pendyala and Kitamura 2004; Thill and Thomas 1987).

2.3.3.1 Activity Scheduling

Activity-based models are focused on the person and his/her activities, both in-home and out-of-home, within the context of that person's constraints (temporal, spatial, and relational). They are designed to explicitly consider how these constraints impact decisions of which activities to participate in and where (the location of the activity). If the chosen activity locations are outside the home, travel is necessary to reach those destinations and perform those activities. Other constraints recognized in the scheduling process include work requirements, the needs of other household members, and available modes of travel, as well as choices of where the activities will take place (Bhat and Koppelman 1999; Ettema and Timmermans 1997; Meyer and Miller 2001).

The theoretical foundation for activity-based modeling efforts comes from three key assumptions: (1) there is a link between activities and travel, (2) the decision to participate in activities is rationally determined within the context of temporal, spatial, and relational constraints, and (3) there is an activity hierarchy considered when scheduling activities. Behaviorally, this means that individuals will consider all that they must or want to accomplish in a given day and where to accomplish them, subject to these constraints, available modes, and time considerations. They then schedule their

activities and travel as necessary in order to carry out their daily plan (Ettema and Timmermans 1997, Bhat and Koppelman 1999). In these activity-based models, the core activities are set, with the secondary activities then scheduled "opportunistically" around them (Bhat and Singh 2000; Lee 2001). This means that for commuters, the work activity is set, then trips to the grocery store or dry cleaner scheduled around the work trip, which is consistent with patterns noted in the data.

2.3.3.2 Structure of Trip Chains

Understanding the structure of trip chains, why trips are chained and which trips are chained can help improve modeling accuracy and the sensitivity of forecasts (Schultz 1996). Some argue that chained trips should be the principal unit of analysis in travel demand modeling (Jou and Mahmassani 1997). In terms of why trips are chained, Adler and Ben-Akiva (1979) found that trip chains are created when two or more activities correspond in space and time or are sequential in nature (pick up child from school and take to dentist). When arranging trips, stops to serve passengers are most likely to be scheduled first, and shopping trips are least likely to be first (Misra and Bhat 2000).

This interface among trips has been studied in depth. Goulias et al (1992) estimate the likelihood for each trip of a given purpose being combined with others into a trip chain. They find that work, shopping, and personal business activities are more likely to be chained together than trips for school or social activities. Looking only at workers, Jou and Mahmassani (1997) investigate the number of trips per chain, the duration of stops, spatial characteristics, and day-to-day variability in travel. In doing so, they show that afternoon stops tended to be longer in duration and less routine. With

regard to non-workers, Misra and Bhat (2000) find that shopping stops were most likely to be chained, and trips to serve passengers least likely to be chained.

From this body of literature, we obtain solid insight into the behavioral process of scheduling activities and how trip chaining results. We also see how the activities are arranged, and differences based on travel by workers vs. non-workers. These earlier studies extend our knowledge of trip chaining by focusing on the mechanics of the phenomenon.

2.3.4 Analysis to Support Policy

The study of trip chaining to support policy analysis has focused on trip-chaining largely because by including non-work trips as part of the daily commute, the traditional commute no longer exists for many workers. The literature investigates factors influencing trip chaining in order to strengthen or meet VMT reduction goals. In doing so, three main themes are considered: the need to consider all portions of the commute (non-work as well as work purposes), the implications for working women, and the conflict between trip chaining and carpooling.

Strathman et al (1994) cautions against focusing solely on the work trip when evaluating congestion-related policies, as it ignores the impact of linked non-work trips on the decision-making process of the commuter. In their analysis, they find that programs focused on increasing vehicle occupancy would have the greatest effect on congestion mitigation, as carpooling requires the rescheduling of non-work trips previously linked to the commute trip. This conclusion, however, ignores the constraints underlying those non-work trips – while non-work trips for shopping and personal

business could be rescheduled, those associated with childcare are an integral part of the ability of the worker to make the commute.

Policies that seek to reduce VMT through mode or schedule shifts result in direct significant time and indirect financial penalties for women (particularly working mothers) which are not offset by transit or carpool incentives (Rosenbloom 1993). Given the higher dependence on the automobile in order to accomplish children and household responsibilities, policies that impose a price on travel (via tolls, parking, or other means) will be of greater burden for women because they tend to earn lower incomes (Bianco 1996; Rosenbloom 1993). In addition, safety concerns influence the distance that women are likely to walk after parking to reach their destinations (Bianco and Lawson 1986). Thus, Bianco and Lawson (1986) conclude that programs which "price or otherwise restrict travel should be complemented by strategies that enhance safety and either eliminate the need for trip chains or make them easier." Examples of complements include on-site childcare, enhanced investment in safety for remote parking, and direct financial subsidies that help to offset the financial penalties associated with longer commutes on transit (specifically longer childcare hours).

There remains an inherent conflict between trip chaining and various transportation demand management strategies. Specifically, Wallace et al (2000) found that promoting alternative work schedules and telecommuting would result in more trips chained together. Concas and Winters (2007) found a similar conflict between carpooling and trip chaining, largely because carpooling imposes an additional constraint on how the commuter can arrange activities (presumably because it is an additional inter-

household linkage that must be considered in the scheduling process), resulting in a disjointed arrangement of travel (before and after the carpool trip to work). It is not surprising then that a study of stated adjustments to various transportation control measures found that 60% of commuters who trip chain would not change their travel mode, regardless of the policy intervention. They would, however, adjust their departure time (Pendyala and Kitamura 2004).

2.3.5 Analysis Findings and this Research

A review of current literature benefits this research in five important areas. First, only one study provided an operational definition of trip chaining (McGuckin and Nakamoto 2004). The lack of operational definitions limits the interpretation of differences found across studies, as it is unclear whether the differences come from how the data were treated or the differences in dependent variables. This is clearly an area for future research.

Secondly, there is an established literature on the mechanics of travel pattern formation. Activities are identified based on household needs, destinations determined, and travel plans set for those out-of-home activities. Trip chaining results from corresponding spatial and temporal characteristics of activities. For workers, the work location is a strong anchor about which other activities are planned, explaining why non-work activities are so easily absorbed into the commute. Non-workers exhibit different travel patterns, largely because of the differences in time constraints and the lack of the work anchor. Understanding how trip chaining comes about helps in both identifying influencers as well as identifying policy implications of this travel pattern.

A third finding is that the literature has established a clear linkage between constraints and trip chaining. This is particularly so for childcare and household responsibilities. Not only are there differences in how the constraints influence trip chaining, but sociodemographic characteristics influence how trips are organized, particularly for workers vs. non-workers. Related to this is the preponderance of findings illustrating the significant differences in trip chaining between men and women, with evidence that household and childcare constraints factor strongly into these differences. This suggests that sex will be a significant variable in this research.

Fourth, the literature confirms that policies which focus only on the traditional commute are in jeopardy. The phenomenon of fitting non-work activities into the work commute is a result of constraints – time constraints, childcare constraints, and household responsibilities. While some non-work activities can be rescheduled, others (particularly those related to household children) cannot. A narrow focus that disregards the influence of constraints on shaping travel patterns results is costly for the traveler as well as the program. In addition, lack of consideration for constraints may cause a gender-bias in terms of program influence.

Finally, trip chaining is in conflict with several transportation control measures. The constraints that influence trip chaining make it very difficult for these commuters to change their travel mode. Carpooling imposes an inter-household linkage constraint and possibly increases VMT because the commuters must return home to then travel out to accomplish those non-work activities that can be rescheduled. In addition, most childcare travel cannot be rescheduled. Alternative work schedules and telecommuting are found

to increase trip chaining levels – meaning that the VMT reduction at the employer site is off-set by increased VMT offsite. This information is important when defining program implications of trip chaining.

2.4 CONCLUSIONS

As indicated in this chapter, travel is a derived demand. We travel to perform desired activities, those activities being a reflection of our desires, our responsibilities, and our constraints. Activity patterns vary because we each have different factors that influence our utility maximization process. These factors may include time, money, involvement of other people, transportation options, and socio-demographic characteristics. Because activity patterns vary, the resulting travel patterns also vary.

Factors that influence activities and travel are also known as constraints. All humans face temporal, spatial, and physical constraints, as well as household, personal, work, and activity setting constraints. Household constraints are a function of household composition and the division of responsibilities across household members. Childcare is a specific household constraint. Personal or demographic constraints include age, work status, and minority status but are largely related to sex as women traditionally bear the larger burden of household responsibilities. Work constraints can be measurable (start time, job type, etc.) but also intangible (job security). Finally, activity setting is comprised of the transportation infrastructure, available destination opportunities, and hours of operation at each destination.

This research seeks to identify the factors that influence trip chaining, largely through an analysis that identifies and categorizes characteristics into these four main

areas of constraint (household, personal, work and activity setting). Because constraints vary across households, it is expected that the segmentation will illustrate differences in how these constraints influence travel.

Most studies ignore the influence of constraints in determining or attempting to influence travel patterns. For example, Strathman et al (2000) recommended that increasing carpooling would have the greatest affect on reducing congestion, recognizing that it would result in rescheduling of non-work activities currently scheduled as part of the work commute. Some non-work activities can be rescheduled, particularly shopping and personal business trips. However, not all non-work trips can be rescheduled, predominantly those related to childcare. By understanding how constraints influence trip chaining, policy recommendations can distinguish between the types of non-work travel to be targeted.

Finally, studies of trip chaining focus largely on commuters only. A few studies consider the travel of non-workers. However, no studies investigate the phenomenon among all working age adults as this research does. By understanding differences between workers and non-workers, it will be possible to see what constraints are equal, regardless of work status, and which fluctuate because of the greater time constraints borne by workers.

Chapter 3 Conceptual Framework and Research Objectives

The question of which factors influence the propensity to trip chain is complex. Existing research fails to answer this question because it focuses primarily on a subset of working age adults – either workers or non-workers but not all working age adults. In addition, the majority of studies focus on the commute trip only. A framework is needed to address the question of which factors influence the propensity to trip chain for all working aged adults which includes both work and non-work travel.

As mentioned in Chapter 1, employer-based VMT reduction programs focus on achieving program goals through moving commuters from their automobiles into shared rides or transit, without regard to the constraints that influenced the commute mode choice in the first place or the non-work activities scheduled into the work commute. In addition, by definition, these programs target workers only, excluding the 63 million non-working adults between the ages of 18 and 65 in the US today. As a result, employer-based programs have enjoyed limited success – an estimated 15% reduction in VMT (Herzog et al 2005) while VMT is estimated to have grown 11% from 1995 to 2001.

Current research has clearly identified the link between household responsibilities and trip chaining, as well as several factors that influence trip chaining (see Chapters 1 and 2). In addition, differences between the trip chaining patterns of workers and non-workers can be identified through a review of the separate studies, particularly regarding how trips are organized. Policy-related studies of trip chaining clearly show a relationship between trip chaining and household responsibilities, as well as internal program conflicts between trip chaining and carpooling or flexible schedules. These

studies, however, fail to consider all travelers of working age, but focus instead on the travel patterns of only workers or non-workers. They also focus predominantly on demographic characteristics of the travelers with secondary interest in the activity setting.

3.1 CONCEPTUAL FRAMEWORK

A conceptual framework developed for application in this study focuses on adult household members (ages 18 to 65) and how their characteristics contribute to their propensity to trip chain on a typical weekday. The underlying activity decision-making process assumed in this framework is that of constrained utility maximization – travelers will seek to maximize the number of activities to be accomplished in a given day subject to household, demographic, work, and activity setting constraints. It also assumes that activities are prioritized, following the established hierarchy of mandatory (work or school), then maintenance (household and childcare related), and then discretionary (leisure) (Mohktarian et al 2006, Gliebe and Koppelman 2002).

The conceptual framework for this research is shown in Figure 3.1. It reflects the theory that constraints cause differences in travel patterns across working age adults, most notably trip chaining propensities. As such, it assumes (1) the constraints can be identified through variables in the national travel survey data set, and (2) a constrained utility maximization decision-making process is used by the traveler to determine what activities to be undertaken on a given day, where, by what travel modes, and in what order. The hypothesis tested here is that both who the traveler is and the context in which travel occurs influence the propensity to trip chain on a given weekday.

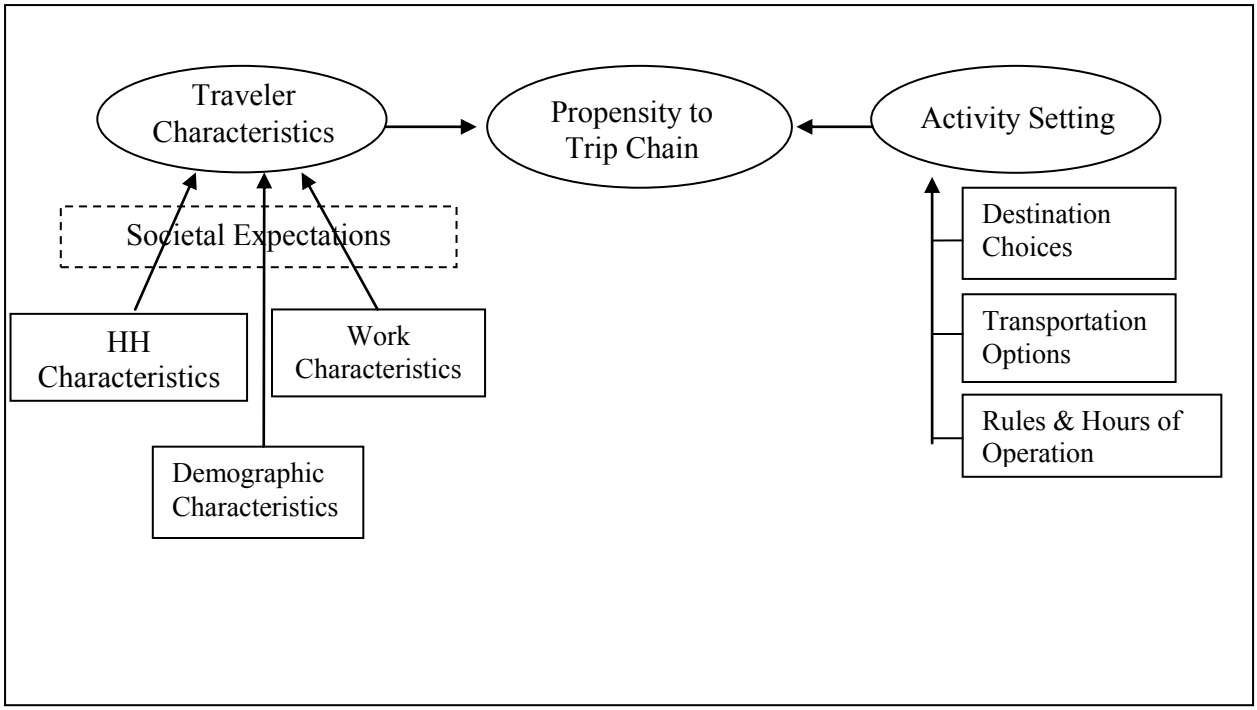

Figure 3.1: Conceptual Framework

This framework reflects the hypothesis that both the traveler's characteristics as well as the activity setting influence the propensity to trip chain on a given weekday. The traveler characteristics are directly measured by **household**, **demographic**, and **work characteristics,** with the recognition that **societal expectations** have an indirect influence on the activities undertaken.

In this framework, the household characteristics describe the household of which the working age adult is a part. The literature suggests these characteristics include those describing the household composition (number of household adults and children) and the resources available to the household (income, number of vehicles, and ratio of vehicles to workers) (Al-Jammal and Parkany 2003, Bhat and Zhao 2002, Bricka 2005, Chapin 1974, Golob 1986, McGuckin and Murakami 1999, McGuckin et al 2005, Misra and Bhat

2000, Strathman et al 1994, Wallace et al 2000, Yalamanchili et al 1999). Earlier versions of this framework included dwelling type and ownership status. However, testing of the segmentation approach showed that these two variables were more reflective of the home location rather than descriptive of the household itself and were thus moved to the activity setting section of the framework.

Demographic characteristics describe the traveler him/herself. These include gender, race, and age. It also includes educational attainment and worker status (Al-Jammal and Parkany 2003, Golob 1986, McGuckin and Murakami 1999, McGuckin et al 2005, Misra and Bhat 2000, Wallace et al 2000, Yalamanchili et al 1999).

Work characteristics include both tangible elements and the intangible consideration of job security. Tangible elements include details about the job: whether the position is full or part-time, occupation, whether the worker can telecommute or has a flexible work schedule, and whether the worker has to drive as part of the job responsibilities. It also includes information about the work day: distance from home to work, work start and end times, length of time spent at work and length of time spent commuting (Bhat 1997a, Damm 1980, McGuckin et al 2005, Wallace et al 2000).

Although not explicitly included in the model, the conceptual framework recognizes that social expectations influence the strength of these various factors. The literature is consistent with regards to women having greater childcare and household responsibilities. Additional studies have found that in dual-income families, the wife tends to work closer to the children. Thus, it is important to recognize this latent variable

as a factor that influences the extent to which the traveler is likely to undertake specific household and childcare activities on a typical weekday.

The **activity setting** describes the environment in which the travel takes place. According to Harvey (1997), the activity setting prescribes the viable locations at which the necessary activities can be conducted (**destination options**) and array of mode choices (**transportation options**), as well as the times during which the activities can take place. In particular, prior studies on trip chaining have linked trip chaining to employment densities, particularly retail and service employment sites, and the work location itself (Adler and Ben-Akiva 1979; Arentze et al. 2001; Bhat 1997a; Damm 1980; Hanson 1980; Wallace, Barnes, and Rutherford 2000). These studies considered only trip chaining characteristics of workers. This research will test the hypothesis that activity setting influences the level of trip chaining of all working age adults, not just workers.

The activity setting is a constraint in that the traveler will filter the activities that need to be accomplished through the destination opportunities, the hours of operation (or time constraints related to specific activities such as picking up children from school), and the transportation infrastructure in the region of travel. So while the household, childcare, and work constraints influence what activities to be performed, the activity setting constraint influences where those activities will take place. Combined, these constraints then influence the propensity to trip chain.

This conceptual framework considers only travel by adults, age 18 to 65. It includes all adults of working age, regardless of work status, to allow for testing of the importance of the work constraint in determining the proportion of trip chaining activity.

Children are excluded from the analysis as their travel patterns are largely dependent on household adults. Senior citizens are excluded both because the majority does not work (whereas adults between 18 and 65 tend to be more equally balanced between those who work and those who do not) and because their overall level of trip making is significantly lower than for adults age 18 to 65. This conceptual framework also focuses exclusively on weekday travel. While an investigation of trip chaining activities on the weekend is planned for future extensions of this research, the research questions explored in this document focus on weekday travel patterns and the impact of trip chaining on the future of commuter-related programs.

In sum, this conceptual framework shows the propensity to trip chain to be a result of the activities that need to be performed and the locations and times at which those activities will take place, which are influenced by demographics, household and work constraint characteristics, and, equally, the activity setting.

3.2 RESEARCH OBJECTIVES

The research questions to be addressed through this dissertation focus on the factors that influence the propensity to trip chain and the resulting implications of that travel pattern on policy. Of particular interest is the extent to which the level of trip chaining can be linked to constraints. Two questions in particular will guide this research:

(1) *What factors influence the level of trip chaining?*

(2) *What implications do these findings have for the success of VMT-reduction initiatives that are designed about the "traditional" weekday commute?*

The first question is designed to address the core question of this research: what factors influence the level of weekday trip chaining undertaken by an adult? This is an important question, as a better understanding of the factors that influence trip chaining will help in understanding the extent to which policy initiatives linked to traditional commute trips will be impacted by these changes in travel patterns. A market segmentation approach will be used to answer this question.

Question 2 will be answered by taking the segmentation results and using them to address a specific question: given what we know about the propensity to trip chain, can VMT reduction programs that focus on the traditional commute still be successful? Obviously, it presumes that the work constraint (or demographic characteristic of being employed) will be found to be significant during the market segmentation. This is an important question to answer as the current policy approach to reducing VMT and improving air quality is through employer-based programs that encourage commuters to use transit or carpool instead of driving alone to work, while the trip chaining literature suggests that the decision to trip chain is primarily associated with household decisions that result in driving alone in order to accomplish non-work activities during the commute. In addition, VMT and travel patterns of non-workers are largely ignored.

In answering this question, a preliminary estimate of program reach will be undertaken through an application of the market segmentation results from Question 1 to Census Data. By focusing on the key determinants of trip chaining, and characteristics of those who still undertake a traditional commute, the number of commuters whose travel can be influenced through employer-based programs will be estimated. Based on the

rates of trip chaining cited in Chapter 1, it is anticipated that less than half of working age adults could be influenced by employer-based VMT reduction programs.

Given that most of the literature regarding trip chaining has focused on how it has changed the commute trip, the second part of the answer to Question 2 requires consideration of how the current program structure must be modified in order to accommodate the changed commute trip as well as travel by non-workers. Alternative program approaches that have been shown to reduce VMT but which are focused on the household will be presented.

This research contributes to the travel behavior literature in a number of significant ways. First, it will be the first analysis of trip chaining to explicitly consider all working aged adults as well as the activity setting. Second, using the knowledge of which factors influence trip chaining, alternatives to the employer-based approach to ensure VMT reduction goals are presented.

Chapter 4 Data Set and Summary

4.1 INTRODUCTION

Current employer-based VMT reduction programs presume a traditional commute between home and work (with no stops) whereas trend data suggest that commuters are increasingly scheduling non-work activities into their work commute. The hypothesis tested in this research is that the propensity to trip chain is a function of both who the traveler is and the activity setting in which the travel takes place, with the underlying theory being that differences in household, person, work, and activity setting constraints explain differences in trip chaining patterns.

Travel behavior theory purports that we travel in order to participate in activities. The specific activities we elect to undertake are a function of whom we are and where we live. The selection of activities to be accomplished on a given day is determined through a constrained utility-maximization process. This research focuses on identifying the constraints or characteristics that influence the trip chaining travel pattern. As such, the demographic characteristics are organized within broader constraint categories of household composition and responsibilities, personal characteristics, and, if employed, work characteristics. The activity setting descriptors reflect viable destination choices and the transportation choices available to make the trips to support the selected activities.

The data set utilized in this analysis is the 2001 National Household Travel Survey (NHTS), which was conducted on behalf of the Federal Highway Administration (FHWA) from April 2001 to May 2002. This is a national survey of household

demographic and travel behavior characteristics that has been conducted every 5 to 8 years since 1969. The data are widely used to understand household travel patterns and implications for transportation policies. The survey data set was enhanced by FHWA with geographic details regarding the household's location, such as population and employment densities. However, details regarding primary land use are not included in the data set. Thus, the NHTS data are supplemented by 2000 Census data to enrich the activity setting description.

In this chapter, the NHTS and supplemental Census data are described and summarized. This includes descriptive summaries of the demographic and activity setting variables in light of who trip chains and a summary of the key factors that are most likely to influence trip chaining (in support of the market segmentation that is introduced in Chapter 5).

4.2 DATA SOURCES

The following is an introduction to the NHTS data and the supplemental Census data. It focuses on the issues relevant to the application of the data to this research question. For more general details on the NHTS, the reader is referred to the survey user's manual.

4.2.1 National Household Travel Survey

The National Household Travel Survey (NHTS) is the only source of national travel behavior statistics and trend data relating to the travel of the American public by all modes of transportation for all trip purposes. It is widely used to study travel behavior-related policy implications at the federal level, including traffic safety, congestion, and

energy consumption (*NHTS Quick Start Guide*). It is a popular resource for transportation researchers investigating a variety of issues, including differences in travel by sex, race, and age groups as well as the more traditionally focused studies on mode usage, trip purpose, and time-of-day travel.

The survey was conducted using standard household travel survey practice in 2001 including random sampling of residential telephone numbers, advance notification of the upcoming survey call, "recruitment" into the study using computer-aided telephone interviewing (CATI), provision of travel diaries for all household members to record their travel for a designated 24-hour period, and retrieval of the travel details also by CATI. A household interview was marked as "completed" when at least 50% of the household members provided travel information. The NHTS data set contains details for 26,038 randomly sampled households and their associated 60,282 members, distributed across all states and major metropolitan areas.

The main data limitations include non-response bias associated with participation by larger households (heavy respondent burden) and coverage bias through the exclusion of non-telephone households (predominantly lower income and minority households). The data are weighted to adjust for these biases as well as unequal probabilities of selection. All results reported in this chapter are weighted using the national sample person file weight, unless otherwise noted.

This research focuses on a subset of survey participants: adult household members of working age who reported travel on a weekday. This represents 24,626 household members or 112,326,515 working age adults when weighted and expanded to

the United States population. The process used to qualify these 24,626 records is summarized in Table 4.1.

National Sample Person File Records	60,282*	Rationale
Excluding those under age 18	-15,236*	Limited constraints and responsibilities as compared to adults, daily activities more often dictated rather than self-selected
Excluding those over age 65	-8,705*	Fewer constraints and more free time, combined with lower mobility rates
Excluding those that did not report any travel on travel day	-3,191*	Trip details needed for dependent variable
Excluding those that reported weekend travel	-8,503*	Different traffic patterns and activity agendas as compared to weekday travelers
Excluding those with administrative variable issues	-21*	Missing data issues
Final Analysis File	24,626*	

*unweighted record counts

Table 4.1: Analysis File Creation

4.2.1.1 Trip Chaining in NHTS

Trip chaining is a phenomenon that is also referred to as "linked trips" or "multi-purpose trip making." While most practitioners agree that trip chaining exists, there is no accepted standard or definition of what exactly constitutes a "trip chain" or how to systematically identify one in a data set (McGuckin et al 2005). Most agree that trip chaining describes the situation where, in lieu of making a series of simple trips from home to a destination and back home, the traveler chains or links those trips together to leave home once, perform all desired activities, then return home.

After consulting an advisory panel (which included this author), the Federal Highway Administration (FHWA) adopted the following operational definition of a "trip chain":

> *A sequence of trips bounded by stops of 30 minutes or less.*
> -McGuckin and Nakamoto 2004, page 1

FHWA then released a linked trip file for the NHTS that contains the same details as the regular trip file as well as flags to denote trip chaining as defined above. In creating this linked trip file, 219,795 of the 642,292 reported trips (one-third, unweighted) are identified as being "chained."

4.2.2 2000 Census Data

For confidentiality reasons, the NHTS does not contain disaggregate details regarding the home locations of the participating households. It does include useful summary variables at the census tract and block group levels, such as population and employment density, metropolitan statistical area (MSA) designation, and whether rail and bus transit services are available to the household. However, there is no land use information available to describe the household's activity setting.

Land use information is included in the analysis data set through proxy, using Table 15 of the 2000 Census Transportation Planning Package (CTPP). Table 15 summarizes the distribution of workers across 14 industries for each census tract in the United States. Using this information, a primary land use was identified for each census tract. For example, if 50% of all workers in census tract X worked in the retail trade industry, the primary land use for tract X is as "retail." The industries include:

1. Agriculture, forestry, fishing and hunting, and mining
2. Construction
3. Manufacturing
4. Wholesale trade
5. Retail trade
6. Transportation and warehousing, and utilities
7. Information
8. Finance, insurance, real estate and rental and leasing
9. Professional, scientific, management, administrative, and waste management services

10. Educational, health and social services
11. Arts, entertainment, recreation, accommodation and food services
12. Other services (excluding public administration)
13. Public administration
14. Armed forces

The census tract data was appended to each record, based on the census tract in which the home was located. In addition to the designation of a primary land use, each record also includes the specific percentages of each industry represented in that tract.

4.3 VARIABLES AND EXPECTATIONS

Using variables from the combined NHTS and Census data sets, segmentation models are developed (in Chapter 5) to test the research hypothesis (trip chaining is a function of who the traveler is and where the traveler lives). The purpose of this section is to review the data set in terms of the variables themselves, provide summary statistics, and expectations regarding each variable's influence on trip chaining. Table 4.2 presents the variables and the summary statistics. Also included is the unit of analysis that each variable represents – the household level, the person level, the census tract level (for the activity setting characteristics), or distance in miles.

As detailed in Section 4.2.1, the data set includes observations representing 24,626 working age adult travelers. These travelers come from 14,791 households. Because the unit of analysis is the traveler, it should be recognized that on average, 1.67 travelers come from the same household. As indicated in the future research section of Chapter 6, one planned extension of this research is to revisit the segmentation approach within the context of a hierarchical model to control for the shared household characteristics among some travelers.

Variable	Variable Type	Unit	Mean	Median	Std Dev
Dependent Variable (Trip Chain)	Binary (1=yes)	Household	0.61	1.00	0.49
# HH Adults	Continuous	Household	2.11	2.00	0.82
# HH Adults squared	Continuous	Household	5.12	4.00	4.44
# HH Children	Continuous	Household	0.81	0.00	1.09
# HH Children squared	Continuous	Household	1.85	0.00	3.80
# HH Vehicles	Continuous	Household	2.31	2.00	1.25
Veh/Worker Ratio	Continuous	Household	1.33	1.00	0.89
Income	Categorical (low/med/high)	Household	2.12	2.00	0.80
Gender	Binary (1=male)	Person	1.50	2.00	0.50
Age	Continuous	Person	39.54	39.00	12.60
Middle Age	Binary (1=yes)	Person	0.26	0.00	0.44
Education	Binary (1=post HS)	Person	1.61	2.00	0.49
Race	Binary (1=minority)	Person	0.29	0.00	0.46
Hispanic Origin	Binary (1=yes)	Person	0.12	0.00	0.33
Worker Status	Binary (1=non-worker)	Person	0.73	1.00	0.44
Time at Work (minutes)	Continuous	Person	269.07	270.00	263.34
Professional Occupation	Binary (1=yes)	Person	0.29	0.00	0.45
Work requires drive car	Binary (1=yes)	Person	0.15	0.00	0.36
Miles from home to work	Continuous	Miles	7.67	1.00	15.58
Population Density	Continuous	Census Tract	1545.47	700.00	1717.47
Hometype	Binary (1=non-single family dwelling)	Census Tract	0.24	0.00	0.43
Employment Density	Continuous	Census Tract	1478.34	750.00	1540.80
Ed/Med Primary HH LU	Binary (1=yes)	Census Tract	0.44	0.00	0.50
Continuum Density	Categorical (1 to 5)	Census Tract	2.96	3.00	1.38
Home Ownership	Binary (1=rent)	Census Tract	0.28	0.00	0.45
Retail Primary HH LU	Binary (1=yes)	Census Tract	0.14	0.00	0.34
Distance HH to transit	Continuous	Miles	9.42	0.50	16.65
% Renter Occupied	Continuous	Census Tract	31.29	30.00	23.33

Table 4.2: Summary of Variables

4.3.1 Household Characteristics

Household characteristics are used as proxies for household and childcare constraints and have figured prominently in research findings. Several studies found the presence of children and other adults in the household significant (Bricka 2005, McGuckin and Murakami 1999, McGuckin et al 2005), as well as the age of the children (Bhat and Zhao 2002, McGuckin et al 2005). In addition, Bhat (1997a) finds that the number of vehicles per worker in a household serves as a constraint in terms of work mode choice. Chapin (1974) and Golob (1986) find life cycle significant, where life cycle is defined as marital status, number and age of children, and whether the children are living at home. Some studies (Golob 1986; Pant and Bullen 1980) find that one-person household travel patterns and trip-chaining tendencies are similar to those in households with multiple adults and no children. Strathman et al (1994) specifically investigate household composition and find that household structure does explain some trip chaining behavior.

Household-level variables from the NHTS were selected for more in-depth consideration, and coded/calculated for application in the market segmentation (Chapter 5). The derivations are summarized in Table 4.3, while the data themselves are summarized in Tables 4.4 and 4.5, both overall as well as based on whether the person trip chains on the travel day.

Variable	Description	Variable Type	Action Taken
binary0	Binary Flag for Presence of Trip Chaining	Derived	=1 if at least 2 trips flagged as belonging to a chain in the chained trip file, else=0
numadult	# HH Adults	Derived	HH Size - # HH Children
numadultsq	HH Adults Squared	Derived	Squared NUMADULT
numkids	# HH Children	Derived	Summed the number of person file records for each household id where age>-1 and <16
numkidssq	HH Children Squared	Derived	Squared NUMKIDS
hhvehcnt	# HH Vehicles	Collected	none
vehwrkr	Ratio of Vehicles to Workers	Derived	HHVEHCNT / WRKCOUNT
rincome3	HH Income	Derived	=1 if HHFAMINC<$30k; =2 if HHFAMINC=$30k - < $60k; =3 if HHFAMINC=$60k+; 1061 missing values imputed by sorting on hhsize, veh ownership, and education level and taking the derived value of the cases immediately before and after

Table 4.3: Household Variables

It should be noted that several variables and variable combinations were tested prior to finalizing the list of household variables in Table 4.3. In testing household composition, various combinations of the key variables describing household size, the age of youngest child, the number of adults and children under the age of 16, and dummy variables to capture household life cycle status were considered. The strongest results were seen with the use of variables describing the number of household adults and children. Other variables tested but excluded from the final model include the number of household workers and the worker-to-adult ratio.

As indicated in Table 4.4, the average household size for trip chainers is 2.95 persons, which is higher than the overall average household size of 2.91 for all working age adults included in this analysis. Trip chainers live in households that average 2.07 adults and 0.88 children. The mean number of adults is lower than the overall average

(2.11) and the number of children is higher than the overall average (0.81). There are also fewer workers in the household on average (1.66 vs. 1.71 overall). The number of household vehicles and vehicles per worker for trip chaining households are average size.

Adults who do not trip chain live in households that are smaller (2.86 vs. 2.91 overall). Their households have more adults and fewer children than average. They also live in households with more workers on average. Non-trip chaining adults live in households with the average number of household vehicles and vehicles per worker.

	Trip Chain		Didn't Chain		All Adults	
	Mean	SE Mean	Mean	SE Mean	Mean	SE Mean
# HH Members	2.95	0.00	2.86	0.00	2.91	0.00
# HH Adults	2.07	0.00	2.17	0.00	2.11	0.00
# HH Children	0.88	0.00	0.69	0.00	0.81	0.00
# HH Workers	1.66	0.00	1.79	0.00	1.71	0.00
# HH Vehicles	2.31	0.00	2.32	0.00	2.31	0.00
Vehicles/Worker	1.33	0.00	1.33	0.00	1.33	0.00

Table 4.4: Summary of Continuous Household Variables

Table 4.5 contains a descriptive summary of the one categorical household variable: income. Overall, 61% of working age adults trip chain on an average weekday. With regard to income, a greater proportion of adults reporting medium and high household income levels trip chain as compared to adults reporting lower incomes (62% of non-low income and 58% of low income, respectively).

Variable	Categories	Trip Chain	Don't Chain	Total
Income	Low	58.1%	41.9%	100.0%
	Medium	62.0%	38.0%	100.0%
	High	61.7%	38.3%	100.0%
Overall		60.8%	39.2%	100.0%

Table 4.5: Summary of Categorical Household Variable

For each household-related variable, expectations regarding that variable's influence on trip chaining are listed in Table 4.6. Specifically, as the number of household adults increases, the expectation is that the propensity to trip chain will decrease as there are more household members to share in the household responsibilities. Similarly, as the vehicle-to-worker ratio increases, the propensity to trip chain is expected to decrease, as fewer household workers have to share a vehicle. As the number of children in the household increases, trip chaining is expected to increase (representing a greater childcare constraint). As household income increases, it is possible for the household to outsource responsibilities (such as eating out, daycare, or dry cleaning), thus trip chaining is expected to increase. Finally, as the number of household vehicles increase, it is unclear how this factor will influence the propensity to trip chain.

Variable	Expectations
Number of Household Adults	-
Number of Household Children	+
Household Income	+
Household Vehicles	Unclear
Vehicle to Worker Ratio	-

Table 4.6: Household Variable Expectations

4.3.2 Person Characteristics

While the household as a unit has specific interactions that influence personal travel, ultimately it is the working age adults that arrange the travel of the household based on related constraints, the activities to be performed on a given day, and the modes and destination options for accomplishing those activities within a set time period. The literature consistently identifies gendered differences with regard to the propensity to trip chain and the trip purposes chained together. Specifically, women are more likely to trip

chain than men and more likely to stop and shop after work (Golob 1986, McGuckin and Murakami 1999, McGuckin et al 2005). Other person-based characteristics include age, education, and whether the person is employed (Golob 1986, McGuckin et al 2005).

The NHTS variables selected to represent the person characteristics are shown in Table 4.7, along with a summary of data manipulations necessary to create these variables and/or prepare them for inclusion in the market segmentation (Chapter 5).

Variable	Description	Variable Type	Action Taken
r_sex	Respondent Sex	Collected	none
r_age	Respondent Age	Collected	none
middleage	Flag for middle-aged respondent	Derived	=1 if R_AGE>34 and <45
b_educ	Binary Education Variable	Derived	=1 if EDUC<2; =2 if EDUC=3-5; =3 if EDUC>5
b_race	Binary Race Variable	Derived	=1 if HHR_RACE<>1, else=0
b_hisp	Binary Hispanic Variable	Derived	=1 if HHR_HISP=1, else=0
worker_bin	Binary Worker Status	Derived	=1 if WORKER=1, else =0

Table 4.7: Person Variables

In addition to the demographic variables listed in Table 4.7, early versions of the model tested variables that summarized the travel behavior characteristics of the working age adults, both regarding the trip chaining mechanics as well as overall levels of activity-making, trip-making, vehicle miles traveled, average trip distance (regardless of mode) and specific trips for the purpose of escorting household members and shopping. After testing various constructions of these variables (both alone and in combination with the demographic variables), the decision was made to exclude these variables from the segmentation. This decision was made largely after reviewing the research objectives –

to identify the factors that influence trip chaining and understand the related policy implications. The travel behavior characteristics identified through these excluded variables are oriented more toward answering questions regarding the mechanics of trip chaining and general travel behavior, which is more in line with a modeling review of the data (rather than a policy-related effort).

The categorical demographic characteristics are summarized in Table 4.8. Consistent with the literature, a higher proportion of females trip chain (65% as compared to 56% of men). With regard to age, middle-aged adults (ages 35 to 44) show the highest trip chaining tendencies, while those ages 18 to 24 were least likely to trip chain. The proportion of adults that trip chain increases as the level of education increases. Only 58% of adults with at most a high school education trip chain, as compared to 62% of those with some education past high school and 64% of those with at least a college degree. Non-minority adults are more likely to trip chain than minority adults (62% as compared to 57%), and Hispanic adults are less likely to trip chain (55% as compared to 62% non-Hispanic adults). Finally, non-workers report the highest levels of trip chaining: 70% as compared to 58% of workers.

Variable	Categories	Trip Chain	Don't Chain	Total
Sex	male	56.2%	43.8%	100.0%
	female	65.4%	34.6%	100.0%
Age	18 to 24	49.5%	50.5%	100.0%
	25 to 34	60.6%	39.4%	100.0%
	35 to 44	64.8%	35.2%	100.0%
	45 to 54	62.6%	37.4%	100.0%
	55 to 65	62.3%	37.7%	100.0%
Education	HS or less	57.9%	42.1%	100.0%
	some post HS	61.7%	38.3%	100.0%
	Bachelors or higher	63.7%	36.3%	100.0%
Race	non-minority	62.1%	37.9%	100.0%
	minority	57.7%	42.3%	100.0%
Hispanic	non-Hispanic	61.6%	38.4%	100.0%
	Hispanic	54.8%	45.2%	100.0%
Worker Status	worker	57.6%	42.4%	100.0%
	not a worker	69.7%	30.3%	100.0%
Overall		60.8%	39.2%	100.0%

Table 4.8: Summary of Categorical Person Variables

Based on this review of the data, the following variables will be included in the analysis, with the expectations as shown in Table 4.9. Specifically, females are expected to have higher trip chaining propensities as compared to men. In addition, middle-aged adults are expected to have higher trip chaining propensities, as are non-minority adults. With regard to education, trip chaining propensities are expected to increase as the reported level of education increases. Being of Hispanic origin and being employed are expected to result in lower trip chaining propensities.

Variable	Expectations
Sex	Female: +
Age	Middle-Aged: +
Race	Non-Minority: +
Hispanic	Hispanic: -
Education	Post High School: +
Worker Status	Employed: -

Table 4.9: Person Variable Expectations

4.3.3 Work Characteristics

Based on the literature, three categorical and two continuous NHTS variables will be used to describe the work characteristics. The derivation of these variables is summarized in Table 4.10. While performing the data manipulations, it became clear that the NHTS data was inconsistent with regards to which adults had data in the work-related variables. Thus, an additional cleaning step was performed on the data prior to finalizing these variables. Specifically, cases where the worker status was "no" but data were present for these variables were reset to remove the extraneous employment data. This extraneous data often results from interviewer error or changes in the respondent's worker status between recruitment and the travel day. While not typical in publicly released data sets, it is a common occurrence in draft or interim data sets.

Variable	Description	Variable Type	Action Taken
hrsatwk	Minutes at Work	Derived	Summed DWELTIME for each trip with WHYTRP01= 11, 12, 13
b_wrkftpt	Binary Work PT/FT Status	Derived	=1 if WKFTPT =2, else=0
hw_miles	Miles from Home to Work	FHWA Derived	FHWA Variable GCDWORK
b_occprof	Binary Professional Occupation	Derived	=1 if OCCAT=4, else=0
b_wrkdrive	Binary Vehicle Required at Work	Derived	=1 if WRKDRIVE=1, else=0

Table 4.10: Work Variables

Variables considered but not included in the model included a binary variable denoting sales occupation, work start and end hours, whether the employee has a flexible work schedule, and employer type.

A summary of the descriptive variables selected for the segmentation are included in Table 4.11. As indicated therein, 58% of working adults trip chained. When

considering differences in trip chaining proportions among workers, those workers who hold part-time jobs trip chain at a higher proportion than full-time workers. This is consistent with literature references to part-time working mothers who are the primary caregivers for the household children. In addition, a higher proportion of workers with professional positions trip chain as compared to those in non-professional positions (60% and 56%, respectively). Finally, workers with jobs requiring vehicles at work trip chain at higher levels than those whose positions do not require vehicles.

Variable	Categories	Trip Chain	Don't Chain	Total
Worker Status	works FT	56.8%	43.2%	100.0%
	works PT	62.8%	37.2%	100.0%
Job Type	Not Professional	56.1%	43.9%	100.0%
	Professional	59.8%	40.2%	100.0%
Car Required at Work	Yes	59.8%	40.2%	100.0%
	No	57.0%	43.0%	100.0%
Overall - Workers		57.6%	42.4%	100.0%
Overall – All Adults		60.8%	39.2%	100.0%

Table 4.11: Summary of Categorical Work Variables

Workers who trip chain work fewer hours on their travel day, as compared to those who did not trip chain (about 65 minutes fewer). In addition, those who trip chain tend to start work about 10 minutes later than those who do not. Finally, workers who trip chain live a mile further from work, on average, than those who do not trip chain.

Variable	Trip Chain		Didn't Chain		Total	
	Mean	SE Mean	Mean	SE Mean	Mean	SE Mean
Minutes at work	439.40	0.03	504.48	0.03	468.76	0.02
Work start time	8.28	0.00	8.18	0.00	8.24	0.00
Miles from home to work	15.37	0.00	14.27	0.00	14.88	0.00

Table 4.12: Summary of Continuous Work Variables

The expected influences on trip chaining for the selected work characteristics variables are shown in Table 4.13. As indicated in the literature and with the descriptive summaries, workers holding part-time jobs are expected to have higher trip chaining propensities, as are those holding professional occupations and for whom a vehicle is required at work. Trip chaining propensities are expected to decline as the length of time at work increases, while they are expected to increase as the distance between home and work increases.

Variable	Expectations
Work Status	Part Time: +
	Full Time: -
Job Type	Professional: +
	Non-Professional: -
Car Required at Work	+
Length of Time at Work	-
Distance from Home to Work	+

Table 4.13: Work Variable Expectations

4.3.4 Activity Setting Characteristics

The term "activity setting" is used here to describe the location in which the travel takes place, including the transportation infrastructure, the destination opportunities, and standard hours of operation for businesses and public entities. According to the underlying hypothesis, the activity setting influences the propensity to trip chain because travel patterns are a function of the destination choices at which activities can be carried out as well as the travel modes available to make those trips. The challenge is in identifying the correct variables to describe the activity setting within a national data set. This challenge was complicated by the fact that most trip chaining studies focus on the characteristics of the traveler and not the activity setting. Of those studies that did

include some geographic characteristics (Adler and Ben-Akiva 1979, Bhat 1997a), employment density was significant, particularly for workers at retail and service employment sites.

The activity setting variables from the NHTS and Census selected for inclusion in the model are shown in Table 4.14, along with details of how they were derived. The HTHUR_NUM variable was designed to identify the household's location along a continuum of urban to rural, thereby allowing insights to be drawn regarding into neighborhood characteristics. As detailed in Appendix Q of the NHTS User's Manual, the categories of the continuum were developed by Claritas and include: Urban, Second City, Suburb, Town, and Rural. It is based on population densities, but also accounts for the context of that density within the surrounding area, which allows for the continuum. In addition to the variables detailing density, land use, and transit availability, two variables that might traditionally be considered household descriptors are included here: home ownership status and dwelling type. Given that the availability of various types of housing stock are related to the land use and density patterns in a region, these variables were moved to this section.

Variable	Description	Variable Type	Action Taken
hthresdn	Housing units per sq mile - tract level	FHWA Derived	none
hteempdn	Jobs per sq mile - tract level	FHWA Derived	none
hthtnrnt	% Renter Occupied - tract level	FHWA Derived	none
hthur_num	Tract level Density Continuum	Derived	Reassigned 5 alphanumeric characters to numeric values, with the values increasing as density increases
regpthh	Distance from home to transit	FHWA Derived	none
retail	Primary Land Use is Retail	Derived	If HH_PRIMARY=retail
ed_med	Primary Land Use is Ed/Medical	Derived	If HH_PRIMARY=education/medical
bhomeown	Home Owner Status	Derived	=1 if HOMEOWN=1, else =0
bhometype	Dwelling Type	Derived	=1 if HOMETYPE=1, else=0

Table 4.14: Activity Setting Variables

Variables considered but not included in the final listing include transportation variables, land use variables, and work-location related variables. A future extension of this research is to repeat the segmentation in specific regions, to identify how to best capture these aspects of the activity setting. The availability of rail and transit in the region, as well as the distance to rail from the home location, were tested in various forms but none approached significance in any model. One possible explanation for this is that the national sample does not include robust enough samples in areas with heavy transit availability (such as New York City or Chicago).

Specific testing for land use influences on trip chaining is a relatively new area of research. Using the census data as described in Section 4.2.2, dummy variables were created to represent the proportion of employment in each of 14 industries in each home census tract. In addition, a second series of dummy variables to indicate the primary land use in each tract were also created and tested. Only the variables indicating primary retail

and education/medical land use types were significant in the modeling process, and exclusion of the other dummy variables did not reduce the model's strength, so they were not included in the final segmentation. Again, investigation of the activity setting at a regional setting should allow refinement of how to best capture land use in future segmentation studies.

The final type of activity setting variables tested were land use and transportation options at the work location (the work census tract). As with the home location variables, these were attached to the data set when a work census tract was available and considered in the segmentation process when the worker status was positive. Again, due to insufficient samples to adequately test the influence of these variables on trip chaining propensities, these variables were excluded from the segmentation analysis with plans to further test in a regional setting.

Descriptive summaries of those variables to be included in the analysis are shown in Tables 4.15 and 4.16. Consistent with the literature, the propensity to trip chain increases as densities at the home location decrease (both population as well as job densities), and in a setting with fewer rental housings (more home owners).

	Trip Chain		Didn't Chain		Total	
	Mean	**SE Mean**	**Mean**	**SE Mean**	**Mean**	**SE Mean**
HH Density in HH Tract	1450.65	0.20	1692.61	0.27	1545.47	0.16
Job Density in HH Tract	1412.81	0.18	1580.03	0.24	1478.34	0.15
% Renter Occupied in HH Tract	30.29	0.00	32.83	0.00	31.29	0.00

Table 4.15: Summary of Continuous Activity Setting Variables

The proportion of trip chaining adults increases as density decreases (similar to the findings above). The levels of trip chaining among adults also varies based on home ownership, with 62% of home owners trip chaining as compared to only 57% of non-home owners, and dwelling type (62% of adults in single-family dwellings trip chain as compared to 57% in other dwelling types).

Variable	Categories	Trip Chain	Don't Chain	Total
Home Location	Urban	56.2%	43.8%	100.0%
	Second City	58.5%	41.5%	100.0%
	Suburb	60.9%	39.1%	100.0%
	Town	64.1%	35.9%	100.0%
	Rural	62.9%	37.1%	100.0%
Home Ownership	Own	62.2%	37.8%	100.0%
	Do Not Own	57.2%	42.8%	100.0%
Dwelling Type	Single Family Dwelling	62.2%	37.8%	100.0%
	Other Dwelling Type	56.6%	43.4%	100.0%
Overall		60.8%	39.2%	100.0%

Table 4.16: Summary of Categorical Activity Setting Variables

Using the hypothesis as a guide, where activity setting should describe the destination and mode options, expectations were set for the activity setting variables. As shown in Table 4.17, as density increases, the propensity to trip chain decreases (whether it's contextual density, population or employment densities). Dwelling type and home ownership status are reflections of the housing market in which the travelers live. Thus, trip chaining is expected to be positively associated with living in a single-family dwelling and owning the own. In addition, trip chaining propensities are expected to be inversely related to the availability of transit. Finally, the influence of land use type is unclear.

Variable	Expectations
Contextual Density	-
Population Density	-
Employment Density	-
Dwelling Type	Single Family +
Home Ownership	Own +
Land Use	Unclear
Transit (Bus) Availability	-

Table 4.17: Activity Setting Variable Expectations

4.4 CONCLUSIONS AND IMPLICATIONS FOR MARKET SEGMENTATION

The key questions to be addressed by this research are the identification of factors influencing trip chaining and understanding the implications that has for employer-based VMT reduction programs. In reviewing the characteristics of who the traveler is (as defined by household, person and work variables) and where the traveler lives (as defined by density, land use, and transit availability factors), the following appear to be the strongest indicators of trip chaining:

- Presence of young children (under the age of 16) in the household
- Worker status
- Home location (in or outside an urban area).

Quantitative testing of these variables will be conducted in Chapter 5 using a logistic regression model, automatic interaction detection, and factor analysis. The resulting market segmentation will be used to identify the key characteristics of trip chainers, thereby answering Research Question 1. This segmentation is necessary to address Research Question 2 (implications for employer-based VMT reduction programs), which will be presented in Chapter 6 along with recommendations for future research.

Chapter 5 Analysis

As indicated in the previous chapter, a descriptive review of the factors or constraints that appear to influence trip chaining suggest that the presence of children under the age of 16 in the household, worker status, and the density of the home location are the strongest predictors of trip chaining. The purpose of this chapter is to confirm these descriptive findings through segmentation, thereby testing the hypothesis that trip chaining is a function of both who the traveler is and where the traveler lives. This will be confirmed through a four step process.

Following a brief introduction to segmentation in Section 5.1, a logistic regression model is developed to test for the significance of the variables selected to describe the household, demographic, work, and activity setting constraints of the working-aged adult in Section 5.2. This will quantitatively identify the factors that influence trip chaining. In Sections 5.3 and 5.4, an *a priori* segmentation will be performed using the two most common approaches to segmentation: automatic interaction detection (AID) and factor analysis. These two approaches validate the findings of the logistic regression. Following this, in Section 5.5, independent logistic regression models will be developed for each segment to provide a more in-depth understanding of variations in the factors that influence trip chaining when holding constant the key variables that define each segment. Applications of the models are presented in Section 5.6. Section 5.7 presents a discussion of the findings in relation to the hypothesis under investigation in this research as stated above and serves as an answer to Research Question 1: What are the factors that influence trip chaining?

5.1 BACKGROUND

As indicated by the descriptive review of the data, characteristics of the 61% of working age adults who trip chain vary, as do those for the 39% who do not trip chain. In order to quantitatively identify the factors that influence trip chaining, a segmentation of working age adults based on trip chaining status is undertaken.

Segmentation is defined as "the process of subdividing the market into groups of customers whose members behave in the same way" (Day 1981) with the goal of arriving at "relatively homogeneous groups" of travelers (Currim 1981). Segmentation is widely used, particularly in marketing where the segments are subsequently used in the development of targeted marketing strategies (Wind 1978). It is also used in transportation research to segment household lifestyle (Zhang and Mohammadian 2006), to forecast mode choice (Bhat 1997b; Outwater et al. 2003), and to identify variations in trip chaining to strengthen travel demand models (Al-Jammal and Parkany 2003). While public policy tends to be of a one-size-fits-all design (Wind 1978), as is the case with the employer-based VMT reduction programs, segmentation can help to develop more appropriate programs targeted to specific commuter groups, thereby realizing greater returns from policy interventions.

There are two general approaches to segmentation: (1) *a priori* and (2) cluster-based or *post hoc* (Green and Krieger 1991; Wind 1978). In *a priori* segmentation, the literature, research objectives, and other factors are used to identify what the segments should be then the appropriate statistical techniques are used to identify differences among groups. In *post-hoc* segmentation, statistical techniques are used to group

respondents based on relevant variables, resulting in segments based on similarities that are identified *post hoc* or after the analysis is completed. In both approaches, the dependent variable is referred to as the "segmentation" and the independent variables are the "descriptors" (Wind 1978 p. 319).

Here, the *a priori* segmentation approach is used. It is appropriate because the research question focuses specifically on identifying factors that influence the propensity to trip chain. The "segmentation" is a binary variable (trip chain yes or no) and the "descriptors" were selected to represent the four types of constraints hypothesized (as detailed in Chapter 4): who the traveler is (household, demographic, and work characteristics) and where the traveler lives (activity setting). As indicated in Chapter 4, trip chaining appears to be most strongly related to the presence of young children in the household, whether or not the adult is employed, and where the household is located (residential densities). The purpose of this chapter is to confirm, through quantitative tools, the factors that influence trip chaining. This is done through a four step process:

1. First, a logistic regression model is developed in Section 5.2 to review the characteristics of all working age adults for statistical significance in explaining trip chaining propensities and identify the most appropriate variables for segmentation.
2. Next, the segmentation scheme is confirmed through Automatic Interaction Detection (AID) in Section 5.3.
3. This segmentation scheme is also confirmed in Section 5.4 through a Factor Analysis.
4. Finally, the segmentation scheme is applied using a series of logistic regression models in Section 5.5.

Each of these steps is discussed more fully as the analysis progresses. The results of the segmentation are summarized in Section 5.6, with an application in Section 5.7.

5.2 BASE MODEL OF ALL WORKING AGE ADULTS

A logistic regression model was developed to test for statistical differences in trip chaining influences based on household, person, work, and activity setting characteristics. In this model, the dependent variable is a binary variable with a value of 1 if the adult trip chains on the travel day and a value of 0 if only simple trips are present in the data for that working aged adult. Of the working age adults in the data set, 61% trip chain on the travel day and 39% do not. Although not fully equal in size (61% trip chaining vs. 39% not), there are sufficient observations in both groups to perform the model estimation.

5.2.1 Base Model Construction

Prior studies investigating trip chaining consistently use descriptives (McGuckin and Murakami 1999, McGuckin et al 2005), regression (Arentze et al. 2001; Goulias, Pendyala, and Kitamura 1992; Hanson 1980), and logit models (Adler and Ben-Akiva 1979, Al-Jammal and Parkany 2003, Misra and Bhat 2000, Strathman et al 1994) as the main analytic tools. The decision to employ a binary logistic regression model in this research is based on two factors. First, the research question focuses on identifying the factors that influence trip chaining. As such, the records belong to one of two groups: those who trip chain and those who do not, suggesting a binary dependent variable. Second, preliminary tests for heteroscedasticity using a linear model suggest a non-linear form is more appropriate to answer the question of how constraints influence travel, thus the logistic regression model.

The selection of variables for consideration in the model is made on the basis of prior studies and a descriptive review of the data (Chapter 4). The variables and expected outcomes for each variable are shown in Table 5.1. As indicated therein, there are four variable groups:

1. **Household Characteristics**: number of adults and children, number of household vehicles, the ratio of vehicles to workers, and income. Based on the literature, trip chaining propensities are expected to increase as the number of children and household income increases. The propensity to trip chain is expected to be negatively correlated with the number of household adults and the vehicle to worker ratio. The influence of household vehicles is unclear – if it is a proxy for income, then it will be positively associated with trip chaining, but if it is a resource constraint, then it will be negatively associated with trip chaining.
2. **Demographic Characteristics**: sex, age, race, ethnic origin, education level, and worker status. Based on the literature base, trip chaining is expected to be positively associated with females, middle-aged adults, those with higher levels of education, and those who do not work. Although not directly addressed in the literature, the propensity to trip chain is expected to be lower for minority and Hispanic working age adults as they tend to have different travel patterns (lower mobility rates and higher shared ride and transit usage) as compared to minority households (Bricka 2004b).
3. **Work Characteristics**: work status, type of position, car required at work, length of time at work, and distance from home to work. The expectations are that trip

chaining is positively associated with part-time workers, those holding professional positions, those that require a vehicle at work, and those that live further from their work site. Trip chaining is expected to be negatively associated with length of time at work on the travel day.

4. **Activity Setting Characteristics**: contextual density, population density, employment density, dwelling type, home ownership status, land use, and transit availability. As residential, employment, and rental densities increase, trip chaining is expected to decrease. Living in a single family dwelling and owning the home, both reflections of the housing stock in which the traveler lives, are expected to be positively associated with trip chaining. Trip chaining is expected to be negatively associated with transit availability. The impact of land use on trip chaining is unclear.

Household Variables	Expectations
Number of Household Adults	-
Number of Household Children	+
Household Income	+
Number of Household Vehicles	Unclear
Vehicle to Worker Ratio	-
Demographic Variables	**Expectations**
Sex	Female: +
Age	Middle-Aged: +
Race	Minority: -
Hispanic	Hispanic: -
Education	Post High School: +
Worker Status	Non-Worker: +
Work Variables	**Expectations**
Work Status	Part Time: + Full Time: -
Type of Position	Professional: + Non-Professional: -
Car Required at Work	+
Length of Time at Work	-
Distance from Home to Work	+
Activity Setting Variables	**Expectations**
Contextual Density	-
Population Density	-
Employment Density	-
Home Ownership	Own +
Dwelling Type	Single Family +
Land Use	Unclear
Transit (Bus) Availability	-

Table 5.1: Model Variable Expectations

5.2.2 Base Model Results

The results of the base logistic regression model show that a working age adult's propensity to trip chain is influenced by several factors. These factors represent all four areas of interest: household, demographic, work, and activity setting characteristics. The goodness of fit is evaluated in Section 5.2.2.1 and the results are summarized in Section 5.2.2.2.

5.2.2.1 Evaluation of Goodness of Fit

In evaluating this model, the first step is to evaluate the adequacy of the overall model or its "goodness of fit" (Gujarati 2003; Long 1997). Depending on the software used to perform logistic regression, common measures of goodness of fit are log likelihood ratios at zero, at constant, and at convergence. This is standard output for software packages such as LIMDEP and GAUSS. Both SAS and SPSS (the two packages used in this analysis) provide the -2 log likelihood measure. For this consideration of goodness of fit, the evaluation measures include two pseudo R^2 measures, one based on the log likelihood and the other a Count R^2. In addition, a statistical comparison of the log likelihoods for the full model vs. those of the separate segment models is undertaken.

With logit models, the conventional measure for goodness of fit (R^2) is not appropriate. Instead, two pseudo R^2 measures can be used: a pseudo R^2 based on the log likelihood (R^2_L) and the Count R^2 (Demaris 1992; Gujarati 2003; Long 1997). The log likelihood R^2 (R^2_L), like the conventional R^2 and a similar measure (McFadden's R^2), ranges from 0 to 1 (Long 1997 p. 104). It is calculated by dividing the log likelihood ratio by minus twice the log likelihood without regressors. For this model, the R^2_L is 0.05. Per Demaris (1992 p. 53), it is not correct to think of this measure as the proportion of variance explained by the model as minus twice the log likelihood is not an "interpretable quantity." This measure tends to "underestimate the proportion of variation explained in the underlying continuous variable, again revealing the loss of

explanatory power that results when the response is measured only at the binary level" (Demaris 1992 p. 54).

A second goodness of fit measure is the Count R^2. This measure is calculated by comparing the ratio of the number of correct predictions by the total number of observations (Gujarati 2003 p. 606). For this model, the Count R^2 is 0.67, suggesting that the model accurately predicts the correct trip chaining status 67% of the time. While the R^2_L is suggested to underestimate the strength of the model, the Count R^2 has been criticized as over-estimating the predictive strength of the model. This is because a proportion of the correct predictions are based on chance rather than modeling results (Long 1997). The true value of the model's goodness of fit therefore lies somewhere between these two measures.

These measures indicate that while the model is useful in estimating the propensity to trip chain, there is room for improvement. It is recognized that goodness of fit is secondary to the expected signs and significance of the coefficients when evaluating logit models (Gujarati 2003 p. 606, Demaris 1992). A future extension of this work is to repeat the analysis at the regional level in order to identify more appropriate activity setting descriptors. Part of that regional test will include an evaluation of goodness of fit to see whether the regional variables improve the model.

A final test of goodness of fit for the base model is to compare the log likelihood at convergence for this base model to the sum of the log likelihoods at convergence for the individual segmentation models. Using a chi-square test, this test finds that the sum of the individual segmentation models is stronger than that of the base model alone. This

means that pursuing a segmentation of travelers is appropriate and stronger results have been obtained than if this base model were the only consideration.

5.2.2.2 Evaluation of Model Results

In interpreting logit models, an important indicator of the model's strength is the expected signs of the coefficients and their statistical significance (Demaris 1992, Gujarati 2003). The results of the base model of all working age adults with regards to the coefficients are discussed in this section and presented in Table 5.2.

Explanatory Variables	All Adults		
	Parameters	**pr>ChiSq**	**Odds Ratio**
Household Characteristics			
# Adults	-0.4066	<.0001	0.666
# Adults Squared	0.0506	<.0001	1.052
# Children	0.3923	<.0001	1.480
# Children Squared	-0.0651	<.0001	0.937
# HH Vehicles	0.0350	0.0340	1.036
Vehicle to Worker Ratio	-0.0597	0.0025	0.942
Demographic Characteristics			
Sex (base=male)	0.2414	<.0001	1.273
Age	0.00914	<.0001	1.009
Middle Age (1 if 35 to 44)	0.1162	0.0006	1.123
Education (base=HS or less)	0.2149	<.0001	1.240
Race (base=non-minority)	-0.0689	0.1111	0.933
Hispanic (base=non-Hispanic)	-0.1436	0.0232	0.866
Worker (base=worker)	0.1508	0.0005	1.163
Work Characteristics			
Time at Work (minutes)	-0.00184	<.0001	0.998
Professional Occupation (base=no)	0.0574	0.0917	1.132
Miles from home to work	0.00208	0.0538	1.004
Activity Setting			
Population Density	-0.00004	<.0001	1.000
Dwelling Type	-0.0596	0.1412	0.942
Intercept	0.2590	0.0359	
% concordant/discordant/tied	65.0% / 34.6% / 0.4%		
-2 Log Likelihood (convergence)	30888.597		

Table 5.2: Logistic Model Results

With regard to **household** characteristics, six of the seven variables tested are significant at the 0.05 critical level: number of household adults and squared, children and squared, vehicles, and vehicle to worker ratio. Only household income is not significant, which is similar to that found by Strathman et al (1994). As shown in Table 5.3, the signs of each significant variable are as expected (positive sign for children, negative signs for adults and vehicle to worker ratio).

Household Variables	Expectations	Outcome
Number of Household Adults	-	-
Number of Household Children	+	+
Household Income	+	Not significant
Number of Household Vehicles	Unclear	+
Vehicle to Worker Ratio	-	-

Table 5.3: Household Variable Outcomes

As supported by the literature, and anticipated based on the descriptive data review, *the presence of children in the household* positively impacts the propensity to trip chain. Specifically, holding all else constant, the propensity to trip chain increases at a decreasing rate with each additional child in the household, as indicated by the positive sign for household children and the negative sign for household children squared. The odds ratio of 1.48 is the highest odds ratio of all variables, suggesting that the presence of children has a strong influence on trip chaining propensities.

These results suggest that it is not just the presence of children that influence the propensity to trip chain, but also *the presence of other household adults*. The propensity to trip chain decreases at an increasing rate with each additional adult in the household, as indicated by the negative sign for household adults and positive sign for household adults

squared. With the lowest odds ratio of all variables (values under 1.0 indicate a negative relationship), this also indicates a strong influence on trip chaining propensities.

The influence of *income* on trip chaining propensities was not significant in this model (as was the case for Golob 1986 as well). While the literature in general suggests that trip chaining increases as income increases, it also statistically links travel by higher income households with recreational trips (Misra and Bhat 2000). Since this analysis focuses on weekday travel only, it is possible that weekday travel and associated trip chaining is influenced more by mandatory activities (such as work and school), thereby limiting the effect of income when studying weekday travel.

The influence of *household vehicle ownership* on trip chaining propensities was unclear prior to executing the model. Misra and Bhat (2000) find vehicle ownership to have a negative influence on trip chaining for non-workers, while Strathman et al (1994) find it to be insignificant for workers, hypothesizing that vehicle ownership to driver ratios are at or above one, indicating saturation and thus little variation in the data. Here, the number of household vehicles is significant and positively associated with trip chaining for working age adults. It is likely that the significance and difference in directionality as compared to prior studies is a result of this model's extension to consider trip chaining propensities by all working age adults, not just workers or non-workers.

The propensity to trip chain decreases as *the vehicle-to-worker ratio* increases. Thus, working age adults living in households with one vehicle and two workers (a ratio of 0.5) have a higher propensity to trip chain than working age adults in households with two vehicles and two workers (a ratio of 1.0). According to Bhat (1997a), as this ratio

increases, there is less competition for vehicles among household workers. It is possible that at low ratios of vehicles to workers, trip chaining may be a coping mechanism (Clifton 2001) both in terms of dropping one worker off as the other travels to work in the vehicle as well as accomplishing errands while the worker has the vehicle.

With regard to **demographic** characteristics, six of the seven variables tested are significant at the 0.05 critical level: sex, age, middle age (dummy variable), education, Hispanic origin, and worker status. Only race was insignificant, which may be indicative of insufficient minority samples in the data set. As shown in Table 5.4, the signs of each significant variable are as expected: (positive signs for females, middle-aged, the higher educated, and non-workers, negative signs for minorities and adults of Hispanic origin).

Demographic Variables	Expectations	Outcome
Sex	Female +	+
Age	Middle-Aged: +	+
Race	Minority: -	Not significant
Hispanic	Hispanic: -	-
Education	Post High School: +	+
Worker Status	Non-Worker: +	+

Table 5.4: Demographic Variable Outcomes

The literature strongly supports the notion that trip chaining propensities are higher for *females*, largely due to the childcare constraints but also because females tend to bear the higher burden of household responsibilities. The results here validate the prior research and extend the earlier findings, which focused only on female workers. It suggests that all females, not just those who work, bear the higher burden of household responsibilities (including childcare when children are present). This variable had the

highest odds ratio among all demographic characteristics, suggesting it has a strong influence on the propensity to trip chain.

There were two *age*-related variables in the model – one that tested trip chaining as a function of age, finding that as age increases, the propensity to trip chain increases. The second age variable was a dummy variable to capture the effect of trip chaining among middle-aged adults (those ages 35 to 44). This variable also has a positive sign, and a stronger odds ratio than the continuous age variable. Combined, these variables tell us that the propensity to trip chain increases with age, but particularly for adults age 35 to 44. Yalamanchili et al (1999) conclude that trip chaining decreases with age. However, their analysis is based only on 100 households, and then only on global positioning system data for one vehicle within each household. However, Golob (1986) studies trip chaining with a more robust sample. He concludes that next to life cycle, age is a highly effective variable for explaining trip chaining, with a positive relationship as was found in this model.

For both *race and minority status*, the literature was largely silent with regards to trip chaining expectations– only Bhat and Misra (2001) tested the influence of race but found it did not have an effect. Indeed, with only 20% of the sample of working age adults having minority status and only 7% of Hispanic descent, it was questionable as to whether there was sufficient variation in the data to test for statistical differences with regards to these variables. The expectations were that minority and Hispanic working age adults would have lower trip chaining propensities. These expectations are based largely on an analysis of the NHTS (Pucher and Renne 2003) which concludes that

minority and Hispanic travelers have lower trip rates, are more likely to travel by transit and, due to resource constraints, have different travel patterns than non-minority households. While it is not possible to determine the influence of race on the propensity to trip chain, the model results do establish that being of Hispanic origin decreases the propensity to trip chain.

In Chapter 4's descriptive review of the data, it was noted that 70% of non-workers trip chain, as compared to only 58% of workers. This was used to set the expectations regarding *the influence of worker status* on trip chaining propensities and the model results confirm this expectation: trip chaining propensities are higher for non-workers than workers. The tendency in transportation research is to study workers and the work commute, thus not much is known about non-workers. In a study of activity-travel patterns of non-workers (who were not students), Bhat and Misra (2001) find that non-worker trips for the purposes of serve passenger and personal business were not likely to be chained with other trips. Misra and Bhat (2000) provide insights into how travel is structured for non-workers, with shopping trips most likely to be chained. However, prior studies speak to the influence of time constraints causing trip chaining patterns among workers (McGuckin et al 2005). Since non-workers do not have work constraints, it is unclear why their trip chaining levels are higher than those of workers. Although the odds ratio for the worker variable was not as high as for other demographic variables, the limited research into travel by non-workers suggests that worker status may be an important segmentation variable.

With regard to **work** characteristics for those who work, only length of time at work was significant at the 0.05criteria level. Holding a professional occupation was significant at the 90% level and distance from home to work was significant at the 95% level. As shown in Table 5.5, the signs of these variables were as expected: trip chaining propensities decrease the more time worked on a given day, while the propensities increase as the distance from home to work increase and if the worker holds a professional position.

Work Variables	Expectations	Outcome
Work Status	Part Time: +	Not Significant
Type of Position	Professional: +	Professional +
Car Required at Work	+	Not Significant
Length of Time at Work	-	-
Distance from Home to Work	+	+

Table 5.5: Work Variable Outcomes

Finally, with regard to **activity setting** characteristics, only population density was significant at the 0.05 criteria level. Dwelling Type (a dummy variable with a base of single family dwellings) was significant at the 0.15 criteria level. As shown in Table 5.6, the signs of these variables were as expected: trip chaining propensities decrease as residential densities increase and for those who live in dwelling types other than Single Family Dwellings. As indicated earlier, the measurement of activity setting characteristics is somewhat exploratory, but the findings regarding density are encouraging and in-line with the literature. The reason for the decline in trip chaining as density increases is related to destination opportunities: those living in less dense areas have fewer destination opportunities. Thus, they may be more likely to incorporate non-

work stops into their work commute, particularly if they commute into a larger metropolitan area with more destination choices.

Activity Setting Variables	Expectations	Outcome
Contextual Density	-	Not Significant
Population Density	-	-
Employment Density	-	Not Significant
Home Ownership	Own +	Not Significant
Dwelling Type	Non-Single Family -	-
Land Use	Unclear	Not Significant
Transit (Bus) Availability	-	Not Significant

Table 5.6: Activity Setting Variable Outcomes

5.2.3 Base Model Discussion

The first step in identifying the factors that influence trip chaining is the development of a logistic regression model. This model has a binary dependent variable (trip chain yes or no) and four vectors of variables – those describing the household, demographic, work, and activity setting characteristics of the working age adult traveling on a typical weekday. Goodness of fit measures suggest that the model is sufficient, but there is room for improvement. Future plans to replicate this study at a regional level should help to refine the independent variables and may improve the overall model statistics.

Regarding the model results, the significant variables have the expected signs, which is a good indication of the model's predictive abilities. Household characteristics influence the propensity to trip chain through the number of children and adults, number of vehicles, and vehicle to worker ratio. Demographic characteristics include sex, age, worker status, and Hispanic origin. Work characteristics include length of time at work on the travel day, as well as distance from home to work and professional occupation.

Finally, density is the strongest activity setting variable to influence trip chaining propensities.

Based on these model results, the variables identified for segmentation are the presence of children and worker status. The presence of children appears to have a strong influence on trip chaining, as was expected. Although worker status does not have as strong an influence, non-workers trip chain more than workers and literature is sparse regarding non-worker travel. The presence of other household adults and education level are other candidates for the segmentation variables in future research.

The selection of these variables is verified through two additional segmentation activities: AID and factor analysis. These are presented in the following sections.

5.3 AUTOMATIC INTERACTION DETECTION

As indicated in Section 5.1, two common approaches to segmentation are automatic interaction detection (AID) and factor analysis. Automatic Interaction Detection or AID is a procedure that "sequentially divides a total sample into subgroups through a series of dichotomous splits" (Maclachlan and Johansson 1981) and is appropriate for segmentation studies as it predicts groups rather than individual responses (Wind 1978, MacLachlan and Johansson 1981). The use of this technique is not common in transportation research, as most analysts favor factor analysis (Al-Jammal and Parkany 2003, Outwater et al 2003).

AID is largely carried out through statistical software packages such as SPSS's Answer Tree (SPSS White Papers). The model is specified according to the dependent variable, independent variables, and weight function. Other specification options include

the statistical level of precision, the number of splits, criterion for the splitting process, and whether the data should be weighted or unweighted. An algorithm determines the splits within the data set based on statistical testing with the Chi Squared statistic.

There are four main criticisms of this technique, largely arising from a misunderstanding about the distinction that it predicts behavior of groups of respondents and not individual respondents. The criticisms deal with the number of observations needed, low correlation ratios, lack of statistical richness, and instability. Each of these is addressed below, drawing from MacLachlan and Johansson (1981 pp. 81-82):

1. This technique is criticized for instability, which can be overcome with "cautious analysis" and large samples.
2. AID requires a large number of observations. However, it is this large sample requirement that helps to minimize issues with instability. A minimum of 1000 observations is recommended (this application includes almost 25,000 samples).
3. The resulting correlation ratios are too low. While correlation ratios are useful when performing disaggregate analyses (individual level), they are not useful when the goal is group-focused as with AID.
4. "AID has been criticized for its lack of statistical richness. This is a misdirected criticism. AID is a partitioning method – it isolates groupings which optimize a criterion function. In that sense, it is no more or less rich in statistical theory than ordinary least squares regression, which is, after all, merely curve fitting."(Maclachlan and Johansson 1981 p. 82)

The AID segmentation was conducted using SPSS Answer Tree Software and employing all variables that also were entered into the development of the logistic regression model in Section 5.2. The results, as shown in Figure 5.1, indicate the key variables associated with differences in trip chaining as identified through the AID technique. Within each box is the distinguishing factor (for example, worker and non-worker), the proportion that trip chain within that category, and the standard deviation associated with that proportion. The first box ("Trip Chained") reflects the overall proportion of trip chaining. The results of the AID suggest that differences in the probability of trip chaining is best explained by studying travel of workers vs. non-workers, with a greater proportion of non-workers trip chaining.

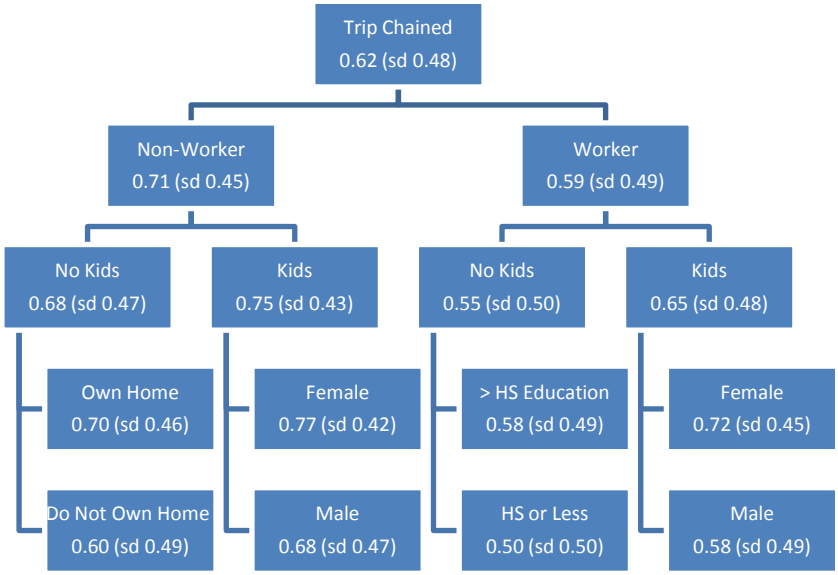

Figure 5.1: AID Segmentation with All Variables

For non-workers, the next strongest predictor is the presence of children under the age of 16 in the household, with higher trip chaining expected for non-workers with children as compared to those without children. The tertiary predictors are home ownership (for those without children in the household), with home owners having higher trip chaining propensities, and sex (for those with children), with women having higher trip chaining propensities as compared to men.

The other half of the tree focuses on predictors for workers. As with non-workers, the secondary predictor is the presence of children, again with those having children under the age of 16 in the household more likely to trip chain that those without children. In terms of tertiary predictors, workers with no children are more likely to trip chain if they have a higher education (above high school) as compared to workers with no children but with at most a high school level of education. For workers with children, the tertiary descriptor is sex, again with females more likely to trip chain than men.

On the basis of this AID segmentation, the main segmentation variables should be the two strongest variables of worker status and presence of children under the age of 16 in the household. These variables were both significant in the logistic regression, and this finding is confirmed through a factor analysis.

5.4 FACTOR ANALYSIS

A second approach to identifying segments or groups of respondents is to conduct a factor analysis. "Factor analysis is a multivariate statistical technique that is concerned with the identification of structure within a set of observed variables. It's appropriate use involves the study of interrelationships among variables in an effort to find a new set of

variables fewer in number than the original variables, which express that which is common among the original variables." (Stewart 1981)

There are two common approaches to factor analysis: principal component analysis (PCA) and principal axis factoring (PAF). PAF is used when the segmentation will feed into a structural equation model. This application utilized PCA, the objective of which is to "determine if the number of factors and the loadings of measured (indicator) variables on them conform to what is expected on the basis of pre-established theory. Indicator variables are selected on the basis of prior theory and factor analysis is used to see if they load as predicted on the expected number of factors" (Garson 2007a). Here, the expectation is that there are four factors: household constraints, personal constraints, work constraints, and activity setting constraints. The same variables as used for the LOGIT and AID analyses were introduced into the process, and the factor analysis was conducted using SPSS.

The process resulted in the identification of 13 factors with Eigenvalues greater than one. In order to determine how many factors to retain for analysis, the Cattell scree test was used (Garson 2007b). The scree plot illustrates the decline in Eigenvalues as the factors are identified. According to this test, all factors above the "elbow" should be retained. In evaluating the scree plot (Figure 5.2), the elbow begins at factor 3 and ends at factor 6. Thus, for this analysis, only factors 1 through 6 were considered, which is within the acceptable range of 5 to 12 factors (Zhang and Mohammadian 2006).

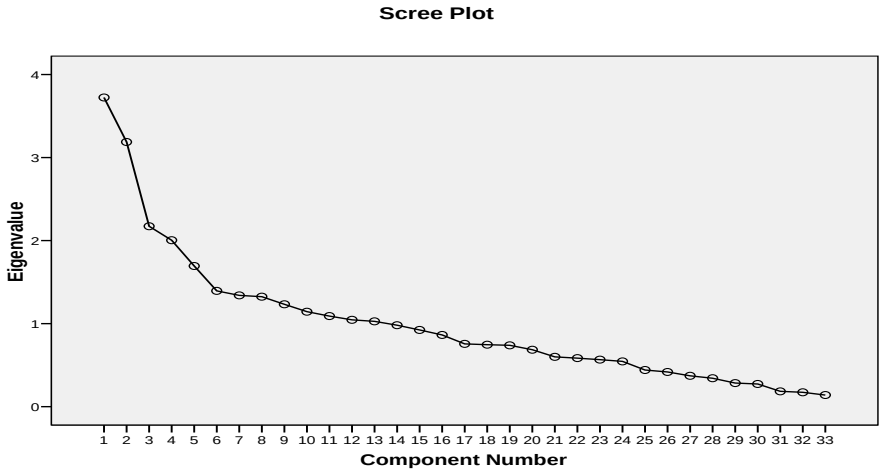

Figure 5.2: Factor Analysis Scree Plot

The output component matrix is shown in Table 5.7. As described in Garson (2007b), the first column is a listing of all variables entered into the analysis. The subsequent columns are the "factors" and the values in the cells are the component loadings (the correlation coefficients between the factors and variables). These values also form the basis of assignment of labels to each factor. In interpreting the component loadings, values of 0.6 or higher are considered "high" and those below 0.4 are considered "low." The analysis thus focuses on component loadings above 0.4.

	1 Work	2 Activity Setting	3 Transport Options	4 Resources	5 Children	6 Children
Length of Time at Work	**0.868**	0.012	0.020	0.028	0.013	0.012
Work Start Time	**0.844**	0.050	0.014	0.069	0.005	0.016
Worker Status (binary)	**0.745**	0.059	-0.044	0.156	-0.043	0.069
Miles from home to work	**0.671**	-0.116	0.015	-0.031	0.071	0.009
Home Ownership (binary)	0.010	**0.768**	-0.066	-0.100	0.113	-0.013
Dwelling type (binary)	0.004	**0.751**	0.110	-0.114	0.040	-0.083
% Renter Occupied	-0.032	**0.731**	0.210	-0.019	-0.037	-0.022
Residential Density	-0.031	**0.546**	**0.665**	0.022	-0.094	-0.012
Employment Density	-0.031	**0.411**	**0.700**	0.065	-0.081	0.003
Rail Availability (binary)	-0.015	0.035	**0.544**	0.042	0.004	0.006
Transit Availability (binary)	0.061	-0.055	**0.531**	-0.075	0.096	-0.009
# HH Adults	-0.064	-0.140	0.042	**0.870**	0.065	-0.063
# HH Workers	0.251	-0.061	0.009	**0.866**	0.079	0.077
# HH Vehicles	0.007	-0.236	-0.111	**0.487**	-0.030	0.003
Youngest Child under age 6	-0.005	-0.028	0.025	-0.014	**0.920**	-0.080
# HH Children	-0.033	-0.078	-0.014	0.100	**0.595**	**0.640**
Middle Age (binary)	0.077	-0.046	0.054	-0.134	0.185	**0.631**
Youngest Child age 6 to 15	0.007	-0.034	-0.023	0.125	-0.236	**0.873**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 14 iterations.
b Only cases for which BINARY0 = 1 are used in the analysis phase.

Table 5.7: Factor Analysis Component Matrix

The factors were named based on the constraint the variables most appropriately described. These include the work constraint (1), activity setting (2), transportation options (3), household resources (4), and the influence of children in the household, both under age 6 (5) and between the ages of 6 and 15 (6). Each of these is discussed below.

The first factor is the **work constraint**. It is defined by length of time at work, work start time, worker status, and miles from home to work. All of the loadings have values above 0.6, which is considered "high." As with the AID technique, the distinction between worker and non-worker appears to have a strong influence trip chaining.

The second factor is comprised of variables that describe the **activity setting** at the home location. This includes home ownership status, dwelling type, and the percent of homes that are renter occupied, which had high loadings, and residential density and employment density, which had moderate loadings. Of the three segmentation methods used in this research, the factor analysis is the only one to adequately capture the essence of the activity setting and its influence on trip chaining as hypothesized. This may be due to the fact that factor analysis can easily accommodate continuous variables with a broad range of values, whereas AID works best with categorical variables.

An unexpected result of the factor analysis was the specific identification of **transportation options** within the activity setting (Factor 3). Both transit and rail availability, which are located in the higher density residential and employment settings, are associated with trip chaining. This intuitively makes sense, as most transit trips (whether bus or rail) entail multiple segments for accessing and egressing the alternative modes of travel.

The fourth factor is labeled "**resources**" as it includes the number of household adults, workers, and vehicles, all of which can energize or constrain the working age adult traveler. The influence of additional household adults and vehicles was also captured in the logistic regression and is discussed above. The influence of household workers has not been significant in either the logistic regression or the AID. It may be a proxy for income (the more workers, presumably the higher the household income). However, all three variables are associated with the distribution of household responsibilities (Vovsha et al 2004) and serve as resources to the adult traveler.

The fifth and sixth factors reflect **the influence of children** on the propensity to trip chain. What is interesting here is that the factors show a distinction between the influence of children on trip chaining based on the age of the youngest child. Although this has not been captured in either the logit or the AID, it is consistent with the findings of Rosenbloom (1987).

The factors appear to successfully identify the constraints identified in the underlying hypothesis (trip chaining is a function of who the traveler is and where they live). In addition, they clearly identify worker status and the presence of young children in the household as significant, consistent with the LOGIT model and the AID analysis. As the first factor loaded, the work constraint was the strongest element of the factor analysis, as was also identified by the AID technique. Unlike the AID, however, activity setting and resource constraints were stronger than the presence of children. This may be a result of the differences in how the techniques handle continuous variables. With AID, continuous variables are evaluated and splits identified, however with a larger "spread" of values, continuous variables tend to be significant at much lower branches of the classification tree. With factor analysis, the focus is on identifying correlations.

The findings of the factor analysis support the hypothesis being tested herein: that trip chaining is a function of who the traveler is and where the traveler lives. In addition, it supports the use of worker status and presence of children as the two main segmentation variables. Conspicuously absent from the results is sex, which has figured so prominently in the literature and in the logistic regression. It was present in the AID at

the tertiary level, and only for those adults with children, which supports the social expectations that women are the primary caregivers.

The final step in the process is to segment the working age adults into four segments (worker with kids, worker no kids, non-worker with kids, and non-worker no kids) and identify the factors that influence trip chaining within each group. This is accomplished in Section 5.5.

5.5 FINAL SEGMENTATION

The logit model, the AID, and the factor analysis all consistently identify two factors that influence trip chaining: worker status and presence of children under the age of 16. Based on these findings, the working age adults were divided into four segments. Table 5.8 shows the number of cases (weighted and unweighted) in each segment, along with the proportion within each group that trip chains. For comparison purposes, the counts and proportion associated with all Working Age Adults is also provided.

Segments	Unweighted N	Weighted N	% Trip Chain
Workers w/ kids	7817	37,048,089	62.5%
Workers no kids	10160	45,298,168	53.6%
Non-worker w/ kids	2625	12,912,068	74.2%
Non-worker no kids	4024	17,068,190	66.2%
All Working Age Adults	24626	112,326,515	60.8%

Table 5.8: Segments

The descriptive summaries of the data in Chapter 4 showed considerable variations in the factors that influenced trip chaining. The goal of this final segmentation is to begin the process of more closely identifying factors that influence trip chaining within each segment. This fine-tuning of our understanding of trip chaining influencers

is necessary to provide more accurate recommendations regarding improvements to the employer-based VMT reduction programs.

Two important findings result from this segment-focused analysis. First, the variables and model construction was based largely upon the literature, which focused mostly on commuters. As a result, the goodness of fit declined for the two non-worker models. Identifying stronger models to identify the factors that influence the propensity to trip chain among non-workers is an area of future research.

Second, the factors that influence trip chaining vary within each market segment. When children are present (workers with children and non-workers with children), the number of children and sex were among the strongest influencers of the propensity to trip chain. For adults with no children under the age of 16 in the household, sex is not a strong indicator (in fact, it is not significant in the non-worker without children model). Instead, the number of household adults, being middle-aged, and education levels influence most strongly the propensity to trip chain. These consistencies support the literature in terms of the childcare constraint, as well as societal expectations that females bear the higher childcare burden. In addition, the influence of the number of household adults for the non-children models reflects the division of non-childcare household responsibilities.

In this section, a brief discussion of the model construction is presented in Section 5.5.1. This is followed by a presentation and evaluation of the logistic regression model results for each segment in Sections 5.5.2 (Workers with Kids), 5.5.3 (Workers no Kids), 5.5.4 (Non-Workers with Kids), and 5.5.5 (Non-Workers no Kids).

5.5.1 Construction of Segment Models

The modeling process for each segment began with dividing the main file of all working age adults into four sub-files, one for each segment based on worker status and presence of children. A logistic regression model was then developed for each segment. Each model used the same variables, except where by definition the variables did not apply (non-workers did not have any work-related variables, adults without children under the age of 16 did not have any child-related variables).

The results of each model, including goodness of fit measures as well as the significance and signs associated with each variable are discussed below. It should be noted that because this segmentation was developed using sub-groups of the data (rather than one model with interaction terms for each segment), it is not possible to directly compare the results of each model as the varying sample sizes result in variations in the the standard errors. However, general conclusions will be drawn in Section 5.6.

5.5.2 Workers with Children Under Age 16

The first segment modeled was that of workers with children under age 16 in the household. The expectations regarding this model are that the influencers can still be organized about who the traveler is and where the travel lives. In addition, the number of children under the age of 16 in the household is expected to be a strong influence on the propensity to trip chain. Finally, strong differences in the influence of sex on trip chaining propensities are expected, given the societal expectations that females are the primary caretakers of the children. The model results are shown in Table 5.9 below.

For this model, the R^2_L is 0.06. Again, it is not correct to think of this measure as the proportion of variance explained by the model as minus twice the log likelihood is not an "interpretable quantity" (Demaris 1992). The Count R^2 is 0.68, suggesting that the model accurately predicts the correct trip chaining status 68% of the time. Again, given the tendency of the R^2_L to under-estimate model fit and the Count R^2 to overestimate fit, the true value of the model's goodness of fit lies somewhere between these two measures. As with the overall model, these measures indicate that while the model is useful in estimating the propensity to trip chain, there is room for improvement.

Explanatory Variables	**Workers with Kids**		
	Parameters	**pr>ChiSq**	**Odds Ratio**
Household Characteristics			
# Adults	-0.8327	<.0001	0.435
# Adults Squared	0.0933	<.0001	1.098
# Children	0.1756	0.0497	1.192
# Children Squared	-0.0274	0.1185	0.973
# HH Vehicles	0.0676	0.0315	1.070
Vehicle to Worker Ratio	-0.1964	<.0001	0.822
Income	0.1133	0.0024	1.120
Demographic Characteristics			
Sex (base=male)	0.5461	<.0001	1.727
Age	0.00804	0.0036	1.008
Education (base=HS or less)	0.1982	0.0003	1.219
Work Characteristics			
Time at Work (minutes)	-0.00177	<.0001	0.998
Miles from home to work	0.00552	0.0014	1.006
Activity Setting			
Employment Density	-0.00008	<.0001	1.000
Ed/Med Primary Land Use	-0.0929	0.0627	0.911
Intercept	0.8968	0.0009	
% concordant/discordant/tied	66.0% / 33.6% / 0.4%		
-2 Log Likelihood (convergence)	9547.124		

Table 5.9: Logistic Model Results for Workers with Kids

In reviewing the model results, all **household** variables were statistically significant at the 0.05 criteria level or higher, with the exception of the number of children squared. This means that the propensity to trip chain increases as the number of household children increases. In addition, as shown in Table 5.10, the signs of the variables were in the expected directions. Specifically, the presence of adults in the household decreases the propensity to trip chain at an increasing rate while the presence of children increases the propensity to trip chain. Income and the number of household vehicles increase the propensity to trip chain, while the vehicle to worker ratio decreases trip chaining levels. Note that this model shows the number of household vehicles to significantly influence trip chaining propensities of workers with children, contrary to the findings of Strathman et al (1994), which found number of vehicles to be insignificant. Finally, in comparing the odds ratio, the influence of number of household adults was stronger than that of the number of children.

Household Variables	Expectations	Outcome
Number of Household Adults	-	-
Number of Household Children	+	+
Household Income	+	+
Number of Household Vehicles	Unclear	+
Vehicle to Worker Ratio	-	-

Table 5.10: Household Variable Outcomes

Demographically, sex, age, and education were significant at the 0.01 criteria level and all found to be positively related to trip chaining. Race and Hispanic origin were not significant. Sex had the highest odds ratio, consistent with prior literature, indicating that females are much more likely to trip chain then males in households with children.

Demographic Variables	Expectations	Outcome
Sex	Female +	+
Age	Middle-Aged: +	+
Race	Minority: -	Not significant
Hispanic	Hispanic: -	Not significant
Education	Post High School: +	+

Table 5.11: Demographic Variable Outcomes

For working parents, this model suggests that the **work** constraint is less about the job characteristics and more about the hours worked and the distance traveled to get to work. As shown in Table 5.12, details about the job itself were not found to be significant. However, length of time at work and distance from home to work were significant and with the expected signs. In addition, compared to the odds ratios for the household and demographic variables, work-related descriptors had relatively small influence on trip chaining.

Work Variables	Expectations	Outcome
Work Status	Part Time: +	Not Significant
Type of Position	Professional: +	Not Significant
Car Required at Work	+	Not Significant
Length of Time at Work	-	-
Distance from Home to Work	+	+

Table 5.12: Work Variable Outcomes

Activity setting does not have a very strong influence on trip chaining for workers with children. As shown in Table 5.13, the only activity setting variables that were significant were employment density and the home location being located in a tract that is primarily medical/educational in nature. Both are found to be negatively correlated with the propensity to trip chain. Although more refined testing is necessary, the significance of the primary land use may suggest that development patterns that

locate schools and medical facilities close to the home may contribute to decreased VMT as they are associated with decreased trip chaining.

Activity Setting Variables	Expectations	Outcome
Contextual Density	-	Not Significant
Population Density	-	Not Significant
Employment Density	-	-
Home Ownership	Own +	Not Significant
Dwelling Type	Non-Single Family -	Not Significant
Land Use	Unclear	Ed/Med -
Transit (Bus) Availability	-	Not Significant

Table 5.13: Activity Setting Variable Outcomes

In sum, this model shows that trip chaining propensities among workers with children are influenced by household, demographic, work, and activity setting characteristics. The strongest factors influencing trip chaining propensities among this group are the number of household adults and sex, with women trip chaining more than men. The variables describing work and activity setting characteristics had the smallest influence on trip chaining propensities.

5.5.3 Workers Without Children Under Age 16

The second model considered was that of workers without children. The expectation is that variables in all four areas will influence the propensity to trip chain. But, without the presence of children, there is expected to be a more equal distribution of household responsibilities by sex, so sex is expected to play a lesser role in this model.

For this model, the R^2_L is 0.05. Again, it is not correct to think of this measure as the proportion of variance explained by the model as minus twice the log likelihood is not an "interpretable quantity" (Demaris 1992). The Count R^2 is 0.62, suggesting that the model accurately predicts the correct trip chaining status 62% of the time. Again, given

the tendency of the R^2_L to under-estimate model fit and the Count R^2 to overestimate fit, the true value of the model's goodness of fit therefore lies somewhere between these two measures.

Explanatory Variables	Workers no Kids		
	Parameters	**pr>ChiSq**	**Odds Ratio**
Household Characteristics			
# Adults	-0.3677	<.0001	0.692
# Adults Squared	0.0449	0.0051	1.046
# HH Vehicles	0.0540	0.0702	1.056
Vehicle to Worker Ratio	-0.1323	0.0008	0.876
Demographic Characteristics			
Sex (base=male)	0.1089	0.0110	1.115
Age	0.00470	0.0056	1.005
Middle Age (1 if 35 to 44)	0.1275	0.0228	1.136
Education (base=HS or less)	0.3050	<.0001	1.357
Race (base=non-minority)	-0.0936	0.1554	0.911
Hispanic (base=non-Hispanic)	-0.1617	0.1205	0.851
Work Characteristics			
Time at Work (minutes)	-0.00190	<.0001	0.998
Car Required at Work (base=yes)	0.0786	0.1408	1.082
Activity Setting			
Population Density	-0.00003	0.1038	1.000
Contextual Density	-0.0386	0.0735	0.962
Intercept	0.8044	<.0001	
% concordant/discordant/tied	64.2% / 35.3% / 0.5%		
-2 Log Likelihood (convergence)	13348.334		

Table 5.14: Logistic Model Results for Workers with No Kids

This model shows that trip chaining propensities for workers without children are still influenced by the four general areas (household, demographic, work, and activity setting). However, the specific variables within each area showing significance and the relative strength of each variable differ from expectations.

In this model, the number of household adults, vehicle to worker ratio, and number of household vehicles all influence the trip chaining propensity of workers

without children under the age of 16. The signs of these variables were as expected. The odds ratios for number of household adults and vehicle to worker ratio were the strongest, suggesting that these two factors act as energizers. The more household adults and the higher the vehicle to worker ratio, the lower the trip chaining propensities. However, workers without children living in households with few adults and a low vehicle to worker ratio have a greater tendency to trip chain.

Household Variables	Expectations	Outcome
Number of Household Adults	-	-
Household Income	+	Not significant
Number of Household Vehicles	Unclear	+
Vehicle to Worker Ratio	-	-

Table 5.15: Household Variable Outcomes

For workers without children, females still have a higher trip chaining propensity, although educational level has a stronger influence on trip chaining than sex.

Demographic Variables	Expectations	Outcome
Sex	Female +	+
Age	Middle-Aged: +	+
Race	Minority: -	Not significant
Hispanic	Hispanic: -	Not significant
Education	Post High School: +	+

Table 5.16: Demographic Variable Outcomes

In terms of **work** constraints, the propensity to trip chain for workers without children is only influenced by the length of time at work on the travel day. No other work-related variables were found to be significant.

Work Variables	Expectations	Outcome
Work Status	Part Time: +	Not Significant
Type of Position	Professional: +	Not Significant
Car Required at Work	+	Not Significant
Length of Time at Work	-	-
Distance from Home to Work	+	Not Significant

Table 5.17: Work Variable Outcomes

Density was the only activity setting variable to be significant in terms of influencing trip chaining propensities of workers without children.

Activity Setting Variables	Expectations	Outcome
Contextual Density	-	-
Population Density	-	-
Employment Density	-	Not Significant
Home Ownership	Own +	Not Significant
Dwelling Type	Non-Single Family -	Not Significant
Land Use	Unclear	Not Significant
Transit (Bus) Availability	-	Not Significant

Table 5.18: Activity Setting Variable Outcomes

In sum, variables in all four areas (household, demographic, work, and activity setting) are found to influence the trip chaining propensities of workers without children under the age of 16. The presence of other household adults, vehicle to worker ratio, and educational levels have the strongest influence on the propensity to trip chain. The work and activity setting characteristics had the lowest influences.

5.5.4 Non-Workers With Children Under Age 16

As indicated earlier, the study of travel by non-workers is a relatively under-studied area in transportation. As a result, the goodness of fit is weaker than for the preceding models, since the selection of variables was driven by a literature base that focused primarily on commuters. In addition, for some variables, while the variables

themselves were statistically significant, the signs were not as expected. This is an area of future research.

For this model, the R^2_L is 0.04. As with the other models, it is not correct to think of this measure as the proportion of variance explained by the model (Demaris 1992). The Count R^2 is 0.75, suggesting that the model accurately predicts the correct trip chaining status 75% of the time. Again, given the tendency of the R^2_L to under-estimate model fit and the Count R^2 to overestimate fit, the true value of the model's goodness of fit therefore lies somewhere between these two measures.

Explanatory Variables	**Non-Workers with Kids**		
	Parameters	**pr>ChiSq**	**Odds Ratio**
Household Characteristics			
# Adults	-0.0775	0.1832	0.925
# Children	0.6378	<.0001	1.892
# Children Squared	-0.0990	0.0002	0.906
Vehicle to Worker Ratio	0.1259	0.0106	1.134
Demographic Characteristics			
Sex (base=male)	0.3729	0.0006	1.452
Age	0.0234	<.0001	1.024
Middle Age (1 if 35 to 44)	0.2371	0.0241	1.268
Activity Setting			
Population Density	-0.00009	0.0054	1.000
Own Home	0.2683	0.0304	1.308
Retail Primary Land Use	-0.3006	0.0193	0.740
Distance to Public Transit	-0.00494	0.0925	0.995
Intercept	-1.0980	0.0026	
% concordant/discordant/tied	63.3% / 36.1% / 0.7%		
-2 Log Likelihood (convergence)	2835.169		

Table 5.19: Logistic Model Results for Non-Workers with Kids

In terms of **household** influences on trip chaining, household composition influences trip chaining among non-workers with children. Trip chaining propensities

increase at a decreasing rate as the number of household children increases. In addition, trip chaining propensities increase as the vehicle to work ratio increases. Surprisingly, the number of household adults is not significant for this model. This is contrary to the findings of Misra and Bhat (2000) and suggests that the non-working adults are indeed primarily responsible for the household and childcare activities, regardless of the availability of any other household adult.

Household Variables	Expectations	Outcome
Number of Household Adults	-	-
Number of Household Children	+	+
Household Income	+	Not significant
Number of Household Vehicles	Unclear	Not significant
Vehicle to Worker Ratio	-	+

Table 5.20: Household Variable Outcomes

As expected, female non-workers with children have a higher trip chaining propensity than their male counterparts. In addition, as age increases, the propensity to trip chain increases. However, for this group, the educational level is not a significant influencer of trip chaining, nor is minority status.

Demographic Variables	Expectations	Outcome
Sex	Female +	+
Age	Middle-Aged: +	+
Race	Minority: -	Not significant
Hispanic	Hispanic: -	Not significant
Education	Post High School: +	Not significant

Table 5.21: Demographic Variable Outcomes

Activity setting influences trip chaining propensities for non-workers with children under the age of 16 through population density (increasing as density decreases) and home ownership. Two interesting notes about the influence of activity setting for this group. First, trip chaining decreases for those non-workers with children who live in

a census tract that is primarily retail. This means that the non-workers are more likely to drive directly to the nearby stores and return home, rather than making other stops while out traveling. Second, the distance to public transit was significant for this group, with trip chaining propensities increasing as the distance decreases (similar to the influence of density).

Activity Setting Variables	Expectations	Outcome
Contextual Density	-	Not Significant
Population Density	-	-
Employment Density	-	Not Significant
Home Ownership	Own +	+
Dwelling Type	Non-Single Family -	Not significant
Land Use	Unclear	Retail -
Distance to Public Transit	-	-

Table 5.22: Activity Setting Variable Outcomes

In sum, trip chaining propensities for non-workers with children under the age of 16 are influenced by household, demographic, and activity setting variables, but not the presence of other household adults. The number of household children, sex (female), and living in an area primarily retail in nature have the strongest influence on trip chaining, while density, distance to public transit, and age had the smallest influences.

5.5.5 Non-Workers Without Children Under Age 16

The least is known about the travel behavior of non-workers without children, and this is reflected in lower measures of goodness of fit for the model, as well as the number of variables found to be insignificant.

For this model, the R^2_L is 0.03. Again, it is not correct to think of this measure as the proportion of variance explained by the model as minus twice the log likelihood is not an "interpretable quantity" (Demaris 1992). The Count R^2 is 0.69, suggesting that the

model accurately predicts the correct trip chaining status 69% of the time. Again, given the tendency of the R^2_L to under-estimate model fit and the Count R^2 to overestimate fit, the true value of the model's goodness of fit therefore lies somewhere between these two measures.

Explanatory Variables	Non-Workers No Kids		
	Parameters	**pr>ChiSq**	**Odds Ratio**
Household Characteristics			
# Adults	-0.3763	0.0186	0.686
# Adults Squared	0.0698	0.0257	1.072
Vehicle to Worker Ratio	0.0546	0.0758	1.056
Demographic Characteristics			
Age	0.0223	<.0001	1.023
Middle Age (1 if 35 to 44)	0.2847	0.0210	1.329
Education (base=HS or less)	0.2310	0.0010	1.260
Hispanic (base=non-Hispanic)	-0.3131	0.0301	0.731
Activity Setting			
% Renters	0.00284	0.1165	1.003
Dwelling Type	-0.2768	0.0048	0.758
Intercept	-0.3285	0.2327	
% concordant/discordant/tied	59.2% / 39.9% / 0.9%		
-2 Log Likelihood (convergence)	4907.462		

Table 5.23: Logistic Model Results for Non-Workers with No Kids

As indicated in the literature, as the number of household adults increases, household responsibilities are shared, thereby decreasing the propensity to trip chain at an increasing rate. This is consistent with a study of non-workers trip chaining undertaken by Misra and Bhat (2000). The vehicle to worker ratio was also significant but at the lower 0.10 critical level. In addition, the sign of this variable is positive, while the expectation was a negative sign. According to Misra and Bhat (2000), the higher vehicle ownership levels for non-workers are associated with lower trip chaining levels.

Household Variables	Expectations	Outcome
Number of Household Adults	-	-
Household Income	+	Not significant
Number of Household Vehicles	Unclear	Not significant
Vehicle to Worker Ratio	-	+

Table 5.24: Household Variable Outcomes

Even more surprising was that gender was not significant in this model, in clear contradiction to the literature. Significant variables, all with the appropriate signs, include age, Hispanic origin, and education.

Demographic Variables	Expectations	Outcome
Sex	Female +	Not significant
Age	Middle-Aged: +	+
Race	Minority: -	Not significant
Hispanic	Hispanic: -	-
Education	Post High School: +	+

Table 5.25: Demographic Variable Outcomes

Finally, with regard to the activity setting, only dwelling type was significant and with the correct sign.

Activity Setting Variables	Expectations	Outcome
Contextual Density	-	Not Significant
Population Density	-	Not Significant
Employment Density	-	Not Significant
Renter Density	-	Not Significant
Home Ownership	Own +	Not Significant
Dwelling Type	Non-Single Family -	-
Land Use	Unclear	Not Significant
Transit (Bus) Availability	-	Not Significant

Table 5.26: Activity Setting Variable Outcomes

In sum, the propensity to trip chain among non-workers without children is influenced most strongly by the number of household adults and education. It is recognized that these results are limited as the variables were identified through the

literature base, which is largely focused on commuters. Future research is needed to better understand trip chaining propensities among this group of non-workers.

5.6 APPLICATION

In an effort to estimate the influence of selected factors on the propensity to trip chain, three scenarios were developed and applied to the appropriate model. In each case, only those variables significant at the 0.05 criteria level were included. The scenarios include:

1. Influence of changes in population density on the propensity to trip chain (considering the base or pooled model),
2. Influence of living in a census tract characterized as educational/medical on the propensity to trip chain (considering the workers with children segment), and
3. Influence of one additional household member on the propensity to trip chain (considering the workers with children segment).

Each scenario is discussed below.

5.6.1 Changes in Population Density

The first scenario tests for how changes in population density influence the propensity to trip chain. The pooled or all working age adult base model is used, focusing on the population density coefficient and including only those variables significant at the 0.05 criteria level.

The base model tested measures:

Propensity to trip chain = 0.2590 – 0.4066 Numadults + 0.0506 Numadults^2 + 0.3923 numkids – 0.0651 numkids^2 + 0.0350 numvehicles – 0.0597 vehwrkr_ratio + 0.2414 gender + 0.00914 age + 0.0062 middleage + 0.2149 education – 0.1436 Hispanic – 0.00184 timeatwork + 0.00208 miles_home2work – 0.00004 density

Where numadults, numadults^2, numkids, numkids^2, numvehicles, vehwrkr_ratio, age, timeatwork, miles_home2work, and density are continuous variables; gender is a binary variable (base=male), middle age is a binary variable (base=no), education is a binary variable (base=HS or less), and Hispanic is a binary variable (base=non-minority).

The scenario tests the influence of density on the propensity to trip chain for a working age adult with the following characteristics:

- Lives in a household comprised of 2 adults (both workers) and 2 children under the age of 16, with 2 vehicles and a vehicle to worker ratio of 1.0. This traveler is a middle-age female (age 40), with a greater than high-school education, of non-Hispanic origin. She spends 8 hours at work, lives 20 miles from work.
- For testing the influence of density, the average density for each of the 5 density continuum stages was estimated as follows:
    - Level 1 (rural) 83.3801 housing units per square mile
    - Level 2 (town) 521.4721 housing units per square mile
    - Level 3 (second city) 1861.526 housing units per square mile
    - Level 4 (suburban) 1671.43 housing units per square mile
    - Level 5 (urban) 4148.651 housing units per square mile.

To test for the influence of these characteristics on the propensity to trip chain, values representing the scenario were input into excel and multiplied by the appropriate coefficient. The values for each variable were then summed to derive the trip chaining propensity. The focus was on the resulting differences in trip chaining propensities related to the differences tested in each scenario (density, specific land uses, and presence of other household adults).

As indicated in Table 5.27, the propensity to trip chain for this working age adult is 0.1358 if she lived in a rural setting. The propensity to trip chain decreases by 0.5% as we move from a rural to a town setting. The difference between a rural and second city setting is a 7.8% decrease, while that between rural and suburbs is a 6.8% decrease. Finally, the difference in trip chaining propensities for this traveler living in a rural vs. an urban setting is a 20.2% decrease.

Scenario 1	Coefficient	Value	Level 1	Level 2	Level 3	Level 4	Level 5
Intercept	0.259	1	0.2590	0.2590	0.2590	0.2590	0.2590
# Adults	-0.4066	2	-0.8132	-0.8132	-0.8132	-0.8132	-0.8132
# Adults Sq	0.0506	4	0.2024	0.2024	0.2024	0.2024	0.2024
# Kids	0.3923	2	0.7846	0.7846	0.7846	0.7846	0.7846
# Kids Sq	-0.0651	4	-0.2604	-0.2604	-0.2604	-0.2604	-0.2604
# Vehicles	0.035	2	0.0700	0.0700	0.0700	0.0700	0.0700
Veh/Wrkr	-0.0597	1	-0.0597	-0.0597	-0.0597	-0.0597	-0.0597
Gender	0.2414	1	0.2414	0.2414	0.2414	0.2414	0.2414
Age	0.00914	40	0.3656	0.3656	0.3656	0.3656	0.3656
MiddleAge	0.0062	1	0.0062	0.0062	0.0062	0.0062	0.0062
Education	0.2149	1	0.2149	0.2149	0.2149	0.2149	0.2149
Hispanic	-0.1436	0	0.0000	0.0000	0.0000	0.0000	0.0000
Time_work	-0.00184	480	-0.8832	-0.8832	-0.8832	-0.8832	-0.8832
Miles (h2w)	0.00208	20	0.0416	0.0416	0.0416	0.0416	0.0416
Density	-0.0004	varies	-0.0334	-0.2086	-0.7446	-0.6686	-1.6595
Trip Chaining Propensity			0.1358	-0.0394	-0.5754	-0.4994	-1.4903
Difference from Level 1				-0.5%	-7.8%	-6.8%	-20.2%

Table 5.27: Influence of Density on Propensity to Trip Chain

For planners and policy makers in large metropolitan regions with commuters traveling in from the outlying counties, the results of this scenario suggest that as the outlying regions grow and densities increase, trip chaining propensities can be expected to decrease. Also, for those developing employer-based programs, the origins or home locations of the employee base are important to consider. If a large proportion of employees live largely outside the urban area, trip chaining propensities should be expected to be higher and traditional programs which assume that workers travel directly from home to work without stops may not be as successful in achieving VMT reduction goals. Proposed alternatives are discussed in Chapter 6.

5.6.2 Influence of Educational/Medical Land Use Type

The second scenario tests for how living in a census tract characterized as primarily educational or medical in land use type influences the propensity to trip chain. The segmented Workers with Children model is used, focusing on the primary land use coefficient and including only those variables significant at the 0.05 criteria level.

The segmented model tested measures:

Propensity to trip chain = 0.8968 – 0.8327 Numadults + 0.0933 $Numadults^2$ + 0.1756 numkids + 0.0676 numvehicles – 0.1964 vehwrkr_ratio + 0.1133 income + 0.5461 gender + 0.00804 age + 0.1982 education– 0.00177 timeatwork + 0.00552 miles_home2work – 0.00008 empdensity – 0.0929 edmed

The scenario tests the influence of living in a census tract with the primary land use of educational/medical on the propensity to trip chain for a working age adult with the following characteristics:

- Lives in a household comprised of 2 adults (both workers) and 2 children under the age of 16, with 2 vehicles and a vehicle to worker ratio of 1.0. The household income is medium. This traveler is a middle-age female (age 40), with a greater than high-school education, of non-Hispanic origin. She spends 8 hours at work, lives 20 miles from work. The employment density is assumed constant at 1478 jobs per square mile, the overall average for the dataset.
- For testing the influence of this land use type, as a dummy variable, two alternatives are tested: yes or no (1 or 0).

As indicated in Table 5.28, the propensity to trip chain for this working age adult is 0.2367 if she lives in a census tract characterized as being primarily educational/medical and 0.3296 if the home census tract is not designated as such. The net difference in trip chaining propensities is 28%.

Scenario 2	Coefficient	Values	Yes	No
Intercept	0.8968	1	0.8968	0.8968
# Adults	-0.8327	2	-1.6654	-1.6654
# Adults Sq	0.0933	4	0.3732	0.3732
# Kids	0.1756	2	0.3512	0.3512
# Vehicles	0.0676	2	0.1352	0.1352
Veh/Wrkr	-0.1964	1	-0.1964	-0.1964
Income	0.1133	2	0.2266	0.2266
Gender	0.5461	1	0.5461	0.5461
Age	0.00804	40	0.3216	0.3216
Education	0.1982	1	0.1982	0.1982
Time_work	-0.00177	480	-0.8496	-0.8496
Miles (h2w)	0.00552	20	0.1104	0.1104
Emp Density	-0.00008	1478	-0.1183	-0.1183
Ed/Med	-0.0929	varies	-0.0929	0.0000
Trip Chain Propensity			0.2367	0.3296

Table 5.28: Influence of Ed/Med Land Use on Propensity to Trip Chain

The Safe Routes to School programs and other Smart Growth Initiatives seek to guide land use planning such that schools are sited within neighborhoods and within walking distances to home. The results of this scenario testing suggest that having schools and medical facilities within the same census tract as the home location result in a 28% decrease in the propensity to trip chain for workers with children. More in-depth analysis is required to determine whether parents are making short trips to the school and back home before proceeding to work or whether the proximity to schools enables

children to travel independently to school, thereby allowing the parent to travel directly to work without the intermediate stop to drop the children off at school. Given the differences in trip chaining propensities between living in this type of census tract and not, it is worth further investigation.

5.6.3 Influence of One Additional Adult Household Member

This scenario examines the influence of household composition on the propensity to trip chain, specifically the difference between being a single-parent and living in a household with one other household adult. The test considers again this influence within the workers with children segment model. Again, only those variables significant at the 0.05 criteria level are included.

The segmented model tested measures:

Propensity to trip chain = 0.8968 – 0.8327 Numadults + 0.0933 Numadults^2 + 0.1756 numkids + 0.0676 numvehicles – 0.1964 vehwrkr_ratio + 0.1133 income + 0.5461 gender + 0.00804 age + 0.1982 education– 0.00177 timeatwork + 0.00552 miles_home2work – 0.00008 empdensity – 0.0929 edmed

The scenario tests the influence of having one additional household adult on the propensity to trip chain for a working age adult with the following characteristics:

- Lives in a household comprised of 2 children under the age of 16, with 1 vehicle, a vehicle to worker ratio of 1.0, and low household income. This traveler is a middle-age female (age 40), with a greater than high-school education, of non-Hispanic origin. She spends 8 hours at work, lives 20

miles from work. The employment density is assumed constant at 1478 jobs per square mile, the overall average for the dataset.

- For testing the influence of the presence of a second household adult, three alternatives are tested: 1 Adult, 2 Adults (second adult does not work), and 2 Adults (second adult works – captured in the vehicle-to-worker ratio).

As indicated in Table 5.29, the influence of a second household adult who does not work is significant: a 72% reduction in the propensity to trip chain. If the second adult works, trip chaining decreases but by a smaller margin.

Scenario 3	Coefficient	Values	1 Adult	2 Adults (2^{nd} adult does not work)	2 Adults (2^{nd} adult works)
Intercept	0.8968	1	0.8968	0.8968	0.8968
# Adults	-0.8327	varies	-0.8327	-1.6654	-1.6654
# Adults Sq	0.0933	varies	0.0933	0.3732	0.3732
# Kids	0.1756	2	0.3512	0.3512	0.3512
# Vehicles	0.0676	2	0.1352	0.1352	0.1352
Veh/Wrkr	-0.1964	1	-0.1964	-0.1964	-0.0982
Income	0.1133	1	0.1133	0.1133	0.1133
Gender	0.5461	1	0.5461	0.5461	0.5461
Age	0.00804	40	0.3216	0.3216	0.3216
Education	0.1982	1	0.1982	0.1982	0.1982
Time_work	-0.00177	480	-0.8496	-0.8496	-0.8496
Miles (h2w)	0.00552	20	0.1104	0.1104	0.1104
Emp Density	-0.00008	1478	-0.1183	-0.1183	-0.1183
Ed/Med	-0.0929	0	0.0000	0.0000	0.0000
Trip Chaining Propensity			0.7691	0.2163	0.3145

Table 5.29: Influence of Additional Household Adult on Propensity to Trip Chain

The difference in trip chaining propensities for single-adult vs. multi-adult households has implications for policymakers and employers alike. It is widely known that single parents who work must juggle household, childcare and work responsibilities. This scenario suggests that the difference in burden levels for these single parents is

significantly greater than that for similarly situated adults who live in households with at least one other adult present. The extent to which that second household adult participates in the household and assists with responsibilities has a large bearing on the propensity to trip chain. For employers with a large portion of their workforce being low-income single parents, traditional VMT reduction programs that presume travel directly between home and work will not be as successful due to this higher trip chaining propensity.

5.7 DISCUSSION

The purpose of this analysis was to investigate the factors that influence trip chaining. Specifically, the hypothesis being tested was that trip chaining is a function of both whom the traveler is (household, demographic, and work characteristics) and where the traveler lives (activity setting characteristics). The results of the segmentation show that trip chaining influencers varies across all four segments both in terms of presence as well as statistical strength.

In order to capture the influence of the activity setting on the propensity to trip chain, the activity setting was explicitly recognized in the conceptual framework of this analysis, and the NHTS survey data were supplemented by Census data so that the influence of the primary land use in the home census tract could be tested. Four types of variables were tested: density (population, employment, renter occupied, and a continuum measurement), access to transit (miles from home location to nearest bus stop), land use (using the census data as a proxy), and details about the home itself (ownership status and dwelling type). This analysis found variables in all these areas to

be significant but different indicators were significant in each model. Despite the differences in the variables found to be significant, the relationship was consistent: as density of the home location and the distance from home to transit increases, the propensity to trip chain decreases. For non-workers with children, living in a census tract predominantly comprised of retail is associated with decreased trip chaining. For workers with children, living in a land use characterized as educational/medical is associated with decreased propensities to trip chain. Finally, owning a home and/or living in a single family dwelling tend to be associated with increased levels of trip chaining (consistent with living in lower-density areas). As discussed in the limitations section of Chapter 1, this research is not designed to answer the question of whether trip chaining should be encouraged more or less. Rather, it seeks to identify the factors that influence trip chaining. With respect to the activity setting, it is clear that an inverse relationship exists between density and trip chaining. Further testing is required before conclusions can be drawn regarding desired levels of densities to be pursued by planners. However, what can be said is that for lower density areas, such as the counties on the fringe of a large metropolitan region, Ceteris Paribas, policy makers can expect higher levels of trip chaining among those residents as compared to those living in denser areas.

The strongest factors influencing trip chaining propensities of all working age adults, as identified through three separate segmentation techniques, were presence of children under age 16 and worker status. Other factors included the household characteristics of number of adults and vehicle to worker ratio, the demographic

characteristics of sex, age, and education, the work characteristics of length of time at work and distance to work, and the activity setting characteristic of density.

When considering trip chaining propensities among the four specific segments, the results varied considerably for those with children under age 16 as compared to those without children. For those with children under age 16, the number of children and sex (females) were the strongest influences of trip chaining, regardless of work status. When no children are present, the number of adults and education were significant influencers. Sex was not a strong influencer when there were no children under the age of 16 in the household, which is a significant point of departure from the literature.

This research provides clear and new insights into the factors that influence trip chaining. First, the identification of the influence of other household adults on the trip chaining propensities is an important contribution of this research. Bhat (1997a), Golob (1996), and Strathman et al (1994) all considered household composition as a series of dummy variables but not specifically the number of household adults. McGuckin and Murakami (1999) find the trip chaining propensities of single mothers to be higher than that of single fathers or coupled mothers, but did not test the number of adults as a specific variable, only again household composition. Second, the strong female influence always occurred in tandem with the presence of children, but working age adults in households without children did not show this strong female tendency. Third, work and activity setting characteristics, while present where appropriate, were secondary in strength of influence to household and demographic characteristics. When this research is repeated at the regional setting (to test alternative specifications for the activity

setting), as well as in a hierarchical model or one that explicitly recognizes household interactions, it will be interesting to see if that trend continues as it suggests that regardless of where one lives, their household composition and personal characteristics are the primary influences of trip chaining propensities and not the work or activity setting characteristics. Finally, this research provides new insights into the trip chaining propensities of non-workers – both with and without the presence of children. This is an important contribution to the literature as the study of travel by non-workers has been limited only to an analysis based in the San Francisco area (Misra and Bhat 2000).

Chapter 6 Recommendations and Future Research

6.1 INTRODUCTION

As indicated in this research, the propensity to trip chain is influenced predominantly by household and demographic characteristics of the working age adult, with work and activity setting characteristics also associated with this specific travel pattern. Through an investigation into the factors that influence trip chaining, this research has shown that worker status and the presence of children under the age of 16 have the strongest influence on this travel pattern. When children under the age of 16 are present in the household, sex and the number of children are the strongest influencers of trip chaining propensities regardless of work status. Absent of these children, the propensities of workers and non-workers alike to trip chain are influenced by the number of adults in the household and educational attainment.

The purpose of this chapter is to review these trip chaining influencers in light of the current employer-based VMT reduction programs, which seek to decrease VMT through a presumed flexibility on the part of the worker to change the commute mode, and trip chaining trends, which show an increasing proportion of non-work activities being scheduled into the work commute. The details in Section 6.2 (an estimation of current program "reach" is presented) and Section 6.3 (a discussion of how these travel characteristics could be used to enhance the current program) form the answer to Research Question 2: What are the program implications of these trends? Section 6.4 presents preliminary ideas for consideration in terms of alternative program options.

Future research is identified in Section 6.5, and general conclusions are presented in Section 6.6.

6.2 ESTIMATION OF CURRENT PROGRAM "REACH"

Since the 1990 Clean Air Act, Federal resources have supported programs that seek to improve air quality through specific transportation control measures. These measures include infrastructure improvements, mode-specific improvements (such as increasing transit service and decreasing cold-starts of automobiles), and employer-based programs to reduce VMT. The employer-based programs promote the use of alternative commute modes, such as shared ride and transit, and provide incentives to those who contribute to VMT reduction goals through the use of these alternative modes.

In the identification of factors that influence trip chaining, this research sought to address the gap between programs focused on changing the traditional commute mode and a growing non-traditional travel pattern (trip chaining) where commuters are accomplishing non-work activities as part of their daily commute. The purpose of this section is to apply the knowledge gleaned from the market segmentation in order to estimate the program reach in light of these changing travel patterns. Program reach is determined in two areas: non-workers and workers.

By definition, employer-based programs target workers only. Of the estimated 174 million working age adults in the United States, 63 million do not work. These 63 million workers generate 25% of average weekday VMT and 70% trip chain as they go about their daily activities. Their travel patterns, mode choices, and resulting vehicular emissions are outside the reach of the current programs.

In order to estimate the current program reach for the 111 million workers in the United States, it is necessary to consider the extent to which commuters still have a traditional commute (defined as traveling directly between home and work with no stops along the way). According to the NHTS, 58% of all workers trip chain. This means that the remaining 42% do not, and therefore are assumed to have a traditional commute. The goal in estimating program reach is to consider what types of commuters have a traditional commute so that as employers design their programs, they can consider their work force and determine whether the typical employer-based programs will be successful or if alternative program elements should be considered.

These traditional commuters can be identified as those showing characteristics associated with lower levels of trip chaining propensities in the segmentation. Focusing on the segmentation results for workers (with and without children) will help to identify the strongest characteristics, although it should be recognized that given the inter-related nature of the variables, this estimation of program reach is a generalization only.

According to the segmentation results for workers with children under the age of 16 in the household, the strongest influencers of trip chaining were the number of household adults and sex of the worker. Trip chaining propensities were highest for females, workers with higher educational attainment, and the number of children in the household. They were lowest for households with more than one adult and a higher vehicle to worker ratio. Given the distribution of responsibilities within each household, particularly with regard to household maintenance and childcare, it is reasonable to expect that some workers with children commute in the traditional fashion.

For workers with no young children in the household, the presence of other household adults, the vehicle to worker ratio, and educational attainment were the strongest predictors of trip chaining. Trip chaining propensities were highest for those with higher educational attainment and those ages 35 to 44. Propensities were lowest for those with more than one household adult and higher vehicle to worker ratios.

Common to both groups is the fact that propensities are lower for those with more than one household adult and high vehicle to worker ratios. Using the characteristics of (1) do not trip chain, (2) being a worker, (3) living in a household with more than one adult, and (4) having a vehicle to worker ratio of at least 1.0, it is possible to identify what proportion of workers in the NHTS have these characteristics.

In terms of all workers in the data set, the proportion with these four characteristics total 30% of all workers (and 27% of all working age adults). This is less than the 42% of all workers known to not trip chain, but is a reasonable approximation using characteristics known to influence trip chaining.

Therefore, the estimated program reach for current employer-based VMT reduction programs is between 30 and 42% of all workers. As indicated earlier, of the 174 million working age adults in the United States, 111 million are workers. A program reach of 30 to 42% means that somewhere between 33.3 and 46.6 million workers commute in the traditional manner and are eligible targets for changing their mode of travel.

While somewhere between 33.3 and 46.6 million workers fall within the reach of the traditional employer-based VMT reduction programs, this means that between 64.4

and 77.7 million workers (58 to 70%) do not. Through a slight refocusing of the program goals, it is possible to still achieve VMT reduction goals among these commuters. This is discussed in the next section, while a revised program that would include all 174 million working age adults is presented in Section 6.4.

6.3 ACCOMMODATING TRIP CHAINING WITHIN THE CURRENT PROGRAM

According to this study, between 64.4 and 77.7 million workers do not commute in the traditional fashion. Many of these trip chain as part of their daily commute, presumably due to time constraints and other factors (largely the presence of children and other household responsibilities). This decreased flexibility suggests that they are not good candidates for traditional VMT reduction programs. They are, however, candidates for VMT elimination strategies. VMT elimination strategies are those that seek to reduce VMT through the elimination of trips, rather than seeking to reduce VMT through mode shift. The main tool for eliminating trips is through offering amenities at the worksite that are suitable substitutions for off-site destinations to which workers would otherwise travel.

Most research on the trip chaining phenomenon points to the fact that the commute trip is changing: workers are taking care of non-work responsibilities on the way to and from work (McGuckin and Murakami 1999, Strathman et al 2000, McGuckin et al 2005). These non-work responsibilities include childcare (dropping off at daycares and schools), banking, stopping at the post office or for coffee, and shopping (Bianco and Lawson 1996, Wallace et al 2000, Bricka 2004a). In addition, employees who go off-site for food tend to run other errands while out of the office in mid-day trip chains (Wallace

et al 2000). An extension of the current employer-based programs should be to provide incentives to employers to provide amenities in line with these types of non-work stops made by commuters, particularly some type of food service, banking (ATM machine), postal services, on-site daycares, and a convenience store. An added benefit of improved employer amenities is these VMT elimination strategies will reduce VMT among the trip chaining commuters as well as the commuters that do not trip chain – reaping even greater reductions in VMT than if the main strategy is only seeking mode shift.

6.4 PROGRAM EXPANSION OPPORTUNITY

In addition to continuing the employer-based VMT reduction programs with a stronger focus on employer amenities that could eliminate VMT, the findings of this research suggest a program expansion opportunity: that of a household-based program to complement the existing employer-based programs (Strathman et al 1994, McGuckin et al 2005) to reach both working and non-working adults, as well as non-work trips. Similar to programs that encourage households to conserve water and electricity, a household-based program could encourage households to conserve VMT.

The advantages to a household-based approach include the following: first, they include by definition all 174 million working-aged adults, not just the 33.3 to 46.6 million commuters who are the target of the current program. With a larger "reach," greater returns in terms of VMT reduction could be realized. Second, with a household focus, these programs automatically account for the intra-household interactions and responsibility allocation that determine mode choice and travel patterns. By taking these constraints into account, tailored marketing programs (based on household composition

and lifecycle status) could be developed to educate citizens of appropriate VMT reduction techniques. Given that trip chaining is largely a life cycle phenomenon, strongest among households with younger children, and decreasing as the children age, household promotions could be targeted based on the age of the youngest child, focusing first on more efficient travel patterns, followed by introducing the information necessary to try commute mode changes, and enforced with benefits to encourage higher levels of contribution to VMT reduction.

A household-based program would support the theories underlying travel behavior. First, we travel to participate in activities (Ettema and Timmermans 1997). Second, and most important for this research, household members are constrained in the activities in which they can participate due to household, personal, work, and activity setting constraints (Hagerstrand 1970). By taking into account household composition and other constraints, the current VMT reduction marketing focus that relies only on travel time and travel cost can be expanded and better reflect reality for most US households.

In studying the effects of trip chaining, several authors have suggested this focus. According to Strathman et al (1994 p. 40), the complexity of the work commute is a function of household composition. Since household composition is often exogenous to transportation policy, it reduces the policy's effectiveness in terms of achieving desired results. Transportation planners and programs are criticized for placing too heavy an emphasis on the work commute, as it also limits program effectiveness (Dittmar 1996; Strathman, Dueker, and Davis 1994). McGuckin et al (2005) recommend research and

policies that focus on household dynamics, with goals of reducing household-level trip making levels rather than person-level trip making.

The most well-known example of a household-based program is the TravelSmart program. TravelSmart is a comprehensive national Australian program that encompasses workplaces, communities, schools, and households to facilitate voluntary changes in travel behavior. An example household program is one that is focused on decreasing reliance on the automobile for the school trip through identifying barriers and solutions with parents, students, and educators as well as individualized marketing direct to the household to educate travelers about transit alternatives. A recent evaluation of the TravelSmart program showed reductions in car travel by a range of 4 to 15%, along with corresponding increases in non-motorized travel (Australian 2005).

Here in the United States, the Portland (OR) SmartTrips program was initiated to "promote ways to get around Portland by transit, walking, biking carpooling and other alternatives to drive alone trips" (Portland 2006). The program focuses on specific geographic areas within Portland, each year adding a new target. They use coordinated individualized marketing and outreach to inform residents and employees of non-auto options. In 2006, the program targeted the Northeast Hub area, resulting in a 13% reduction in drive alone trips from the 7400 participating households (31% of households in the targeted region). A similar program targeting an area near the Interstate MAX light rail line resulted in a 14% decrease in VMT (Socialdata 2005). Evaluation of this program continues, to document the longer-term effects. However, the results of this voluntary household-based program are encouraging.

6.5 FUTURE RESEARCH

This research investigated the hypothesis that trip chaining was a function of who the traveler is and where the traveler lives. It extended the current research by both including all working-aged adults (not just focusing on commuters) as well as by attempting to capture the activity setting for each traveler. The findings show that trip chaining is a function of household, demographic, work, and activity setting characteristics of the traveler. Using market segmentation techniques, it was shown that the main characteristics that distinguish trip chaining characteristics were worker status and whether there were children under the age of 16 in the household. It was also shown that within these four areas, the level and factors influencing trip chaining varied greatly, with non-workers trip chaining at higher proportions than workers. Finally, the results point to two areas in which greater VMT reduction levels can be achieved: through a stronger focus on employer amenities (eliminating VMT for all workers rather than just reducing VMT among those who have a traditional commute) and through a more comprehensive program that targets households (like the Portland SmartTrips or Australian TravelSmart programs).

In addition to these findings, future research on the topic is warranted. This includes the following:

1. *Refinement of the variables to capture the activity setting*. This analysis was conducted at a national level, appropriate for policy-related questions. Using available variables from the NHTS, as well as supplemental census data, indicators of density as well as primary land use were shown to have

significant influence on trip chaining propensities. These indicators could be refined by repeating this study at the regional level, incorporating GIS and land use parcel data to obtain stronger measures of the activity setting – both at home and at the work location. Once these are identified, the national analysis can be repeated to determine whether these regional-generated variables have a better explanatory effect.

2. *Explicit recognition of inter-household linkages*. The current model treats each traveler as an independent observation. Through the use of summary variables derived from the reported travel or the use of a hierarchical model, it would be possible to directly capture the effect of the household characteristics and determine the extent to which the shared household characteristics influence the model results.
3. *Understanding trip chaining within specific population segments*. Much of the trip chaining research has focused on how the phenomenon has changed the work commute, particularly among working mothers. This research suggests that the levels of trip chaining are higher for non-workers than workers. A better understanding of travel among non-workers is needed to understand the implications of this travel pattern, particularly for non-workers without children. In addition, income influences trip chaining level for working parents. Given the resource limitations of the working poor, who often juggle work, childcare, and household responsibilities, a second job for one or both household workers, and much less flexibility regarding work

hours, the question arises of how policy could be shaped to help alleviate some of the constraints faced by this segment of the population.

4. *Identifying other factors that influence the propensity to trip chain*. This research on factors that influence trip chaining propensities relied on data collected through the NHTS. The demographic and travel behavior details used in this analysis are widely available in other regional and statewide household travel surveys conducted to support the update of regional travel demand models. However, the goodness of fit measures for the models developed suggest that factors other than those related to household, demographics, work, and activity setting influence the propensity to trip chain. A proposed extension of this research is to investigate the influence of other factors that might influence the propensity to trip chain but which are not commonly captured through travel surveys. An example of this is personality type. One of the four anchors of the Myers-Briggs personality assessment is the level of structure preferred by individuals (Foundation). Individuals fall somewhere along a spectrum from highly structured (judging) to a flexible lifestyle (perceiving). Those tending toward judging are orderly, make lists of things to be done, and like to have things decided. Those tending toward perceiving like to stay open so that they can respond to change and keep plans to a minimum. From a travel behavior point of view, it is possible that people who participate in these types of surveys are those who tend toward one end of the spectrum, thereby skewing the observed travel

patterns towards their desired level of structure. In addition, those who trip chain may tend toward judging, where the trip chaining results from a highly structured and organized day, begging the question of how perceivers travel patterns differ. This is just one example of a factor external to current travel survey that may be useful in understanding more about this travel pattern.

6.6 CONCLUDING REMARKS

The goal of this research was to identify the factors that influence trip chaining in order to understand the policy implications of this growing travel pattern. Of particular concern was that the success of current employer-based programs is largely reliant upon commuters changing their mode of travel. Mounting evidence shows that commuters are scheduling non-work activities into their commute trips, most likely a coping mechanism to deal with time constraints and household responsibilities.

In conducting this research, several definitional issues regarding trip chaining were identified. In particular, prior studies on trip chaining vary in terms of findings, largely because of differences in focus as expressed by the dependent variable. However, only one study provides an operational definition of trip chaining in terms of how the data were organized prior to the analysis. The effects of different approaches to trip chaining on the outcomes of each study is unknown, but clearly continues to contribute to limited progress in terms of modeling and understanding policy implications as Thill and Thomas put forth in 1987. As a community, transportation analysts need to evaluate the extent to which commonality is needed and the implications for differences in how trips

are chained on the application of our findings. This common definition will also help to advance the development of activity based models.

In addition several important findings have come to light by extending the research to include all working age adults. First, household and demographic characteristics are stronger predictors of trip chaining than work or activity setting characteristics, although all four areas have been shown to influence trip chaining propensities. Second, household composition is perhaps the strongest influencer, with the number of children strongly associated with increased trip chaining and the number of household adults strongly associated with decreased trip chaining. Furthermore, when children are present in the household, females have a much higher propensity to trip chain than when children are not present (regardless of work status). In addition, for non-workers with children, the number of household adults has no impact on trip chaining propensities. Thus the often cited linkage between women and trip chaining is a reflection of household responsibilities, as often hypothesized.

Finally, while the model goodness of fit statistics were not as strong as hoped for, the measures are a clear indicator that travel patterns in general, and trip chaining in particular, are influenced by more than what is obtained in typical household travel surveys. Identifying these alternative influencers may help to improve the results of regional travel demand models, as well as strengthen activity-based modeling and policy initiatives that are based on travel behavior studies.

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Vita

Stacey Golembeski Bricka was born December 1966 in New Jersey, the daughter of Thomas and Barbara Golembeski. She graduated with honors from Sarasota High School in 1985. Stacey then attended Eckerd College in St. Petersburg, Florida, where she met and married Max Bricka in 1988 and received her Bachelor of Arts degree in Economics in 1989. Her education at Eckerd was financed through scholarships and grants from Eckerd College, the Rinker Corporation, the William G. Shelby and Marie Shelby Foundation of Sarasota, and the Sarasota Chapter of the Polish-American Society. She also held a research assistantship position, assisting Dr. Diana Fuguitt with research into soy extruder technologies for developing countries.

After completing her bachelor's degree, she began pursuit of her master's degree in Economics at the University of South Florida's College of Business Administration in the fall of 1989. She received her Master's degree in Economics from USF in December 1991. While pursuing this degree, Stacey worked full-time at the Center for Urban Transportation Research (CUTR), first as a graduate research assistant, then as visiting faculty, finally securing a permanent research faculty position. While at CUTR, she co-authored two publications using the national travel survey data. She also contributed to technical memoranda and project reports on a variety of transportation projects, from travel for the disadvantaged to the evaluation of the first in-vehicle guidance technology (Navteq), to transportation demand management and on-board surveys, and analysis of the national travel survey data on a variety of topics.

Stacey and Max moved to Austin, Texas, in 1994, where their daughter, Traci, was born in 1996. From 1994 to the present, Stacey has worked for NuStats, a consulting firm specializing in travel survey design and primary data collection. While at NuStats,

Stacey has managed almost 40 regional household travel survey projects, with tasks ranging from design to data collection to analysis and reporting. Over her 14 year tenure with NuStats, she has authored and presented multiple conference papers relating to household travel surveys: design, scheduling, non-response, and general results.

Stacey entered the doctoral program in the Community and Regional Planning Program at the University of Texas at Austin in 2003. During her years in the program, she was awarded the University Pre-emptive Recruitment Fellowship, the University Burton Tuition Scholarship (twice), and the US Environmental Protection Agency's Science to Achieve Results Fellowship. She held a research assistantship under Dr. Chandra Bhat in the College of Engineering, working on two projects for the Texas Department of Transportation (using global positioning system technology to replace telephone survey data in household travel surveys and developing an accessibility measure for transit). She also held a teaching assistantship in the Fall of 2006 for the Quantitative Methods class, taught by Dr. Terry Kahn. While at UT, Stacey presented three times at the Association for Collegiate Schools of Planning annual conferences, each paper contributing in some way to this dissertation. She co-authored a publication on trip-underreporting with Dr. Bhat. She also guest lectured several times for classes in the planning and engineering programs, with a focus on survey research.

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